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Report of the Benchmark Workshop on *Nephrops* Stocks (WK*NEPH*)

25 February–1 March 2013

Lysekil, Sweden

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 Executive summary

This benchmark workshop continued and consolidated developments over a number of years, documented in particular in WK*NEPH*2009 and SGNEPS2012, as well as several reports of WGNSSK and WGCSE. The key methodology was established in WK*NEPH*2009, but data and procedures have been refined since then.

The following FUs 6 (Farn Deeps), 11 (North Minch), 16 Porcupine), 32 (Devils Hole) and 34 Norwegian Deep) were considered at this meeting. FU 3–4 were withdrawn from the benchmark prior to the meeting due to important developments that will only be completed later this year. A brief presentation of these developments and plans was presented and commented.

The key methodology that is recommended if possible relies on UWTV surveys as a source of absolute biomass estimate, combined with a harvest rate derived from a length based yield and biomass per recruit analysis.

For FUs 6 and 11, established procedures (UWTV based) were refined and updated. For FU 34, there has been a development in the direction of applying the standard procedure based on UWTV surveys, but it was concluded that a change to this approach would still be premature. Developments needed were outlined, with the aim to change approach in the near future. In FU 16 an UWTV based approach was approved. FU 32 is still to be regarded as data-poor. Ways to improve the basis for decision were outlined.

2 Introduction

This benchmark workshop continued and consolidated developments over a number of years, documented in particular in WK*NEPH*2009 and SGNEPS2012, as well as several reports of WGNSSK and WGCSE. The key methodology was established in WK*NEPH*2009, but data and procedures have been refined since then.

The following FUs 6, 11, 16, 32 and 34 were considered at this meeting. FU 3–4 were withdrawn from the benchmark prior to the meeting due to important developments that will only be completed later this year. A brief presentation of these developments and plans was presented. For FUs 6 and 11, established procedures were refined and updated. For FU 34, there has been a development in the direction of applying the standard procedure based on UWTV surveys, but it was concluded that a change to this approach would still be premature. Developments needed were outlined, with the aim to change approach in the near future. In FU 16 an UWTV based approach was approved. FU 32 is still to be regarded as data-poor. Ways to improve the basis for decision were outlined. In the report, there is one section for each FU. Section 3 gives a brief description of the methodology applied, with a brief mention of alternatives and possible future developments. A brief description of plans for FU 3–4 is included in Section 9. Some general comments from the external reviewers are included as Annex 3.

3 Overview of methodology

The method for providing advice for *Nephrops* has evolved over several years. It has long been recognized that the standard assessment-prediction procedure used for finfish is not readily applicable to *Nephrops*. The strategy that has emerged is documented in ICES 2009. This section gives a brief summary of the elements in this strategy, highlighting the sources of data, methods and critical points.

The approach is to use UWTV-surveys to provide an absolute estimate of abundance from which recommended catch and landings are derived according to an accepted harvest rate (HR- catch/biomass). The recommended values for the HR are obtained from length-based yield and biomass per recruit analysis.

For stocks where UWTV-surveys are not available, a procedure has been developed which is also briefly outlined here.

3.1 UWTV-surveys

An UWTV survey counts the number of burrows along-transects. This leads to an estimate of density (numbers per m^2). There are several designs of such surveys, basically a fixed grid design and a stratified random design. These designs have different statistical properties, as described in ICES (2012) (SGNEPS). It has been agreed that CVs <20% are acceptable. Correction factors apply to account for misinterpreting burrows near the edges and for occupancy and identification.

The density is applied to an estimate of the total fishable area. Various methods have been used to estimate the area of the fishing grounds and define the boundaries. In many cases VMS data have been used either using manual interpolation of boundaries our using algorithms such as convex hull to objectively define the boundary. However, using VMS data to estimate the area of can be sensitive to the spatial and temporal resolution of data, especially where the spatial extent of fisheries varies between years. Where there is such variability occurs the union of defined polygons over a number of years is probably preferable to taking an average over the years. An alternative approach using nested grids to define the spatial extent and frequency of trawling impact at and appropriate spatial scale could also be applied in future (Gerritsen *et al.*, 2013).

There is a lower limit to the size of *Nephrops* burrows that can be identified during UWTV surveys. Very small *Nephrops* are thought to be associated with the burrows complexes of adults (Marrs *et al.*, 1996). The size at which *Nephrops* construct burrows of their own is not certain. There are also 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 consensus at WK*NEPH* 2009 (ICES, 2009) was that survey selectivity had an L50 of 17 mm (knife-edge selection with a likely detection range of 15–20 mm). There was no new information available at WK*NEPH* 2013 to revise this estimate. Thus the burrow densities and abundance estimates in numbers from UWTV surveys are for individuals >17 mm in the exploited area.

The procedure outlined here was approved by the previous benchmark (2009) where many of the points above are discussed extensively. The present report concentrates on issues that have been dealt with since then.

3.2 Yield and biomass per recruit

This is calculated for a length-disaggregated population. The method most commonly applied is essentially age structured, but with narrow age intervals that corresponds to a near continuous age–length relation.

Input to this analysis is:

- k and Linf in the von Bertalanffy equation: Mostly from the literature.
- Parameters in the length–weight relationship: Generally estimated from samples.
- Selection at length in the fishery: Generally estimated using a length cohort type analysis.
- Natural mortality at length: Guesstimate.

Males and females grow and behave differently, and therefore the proportion of the sexes in the fishery may vary both seasonally and from year to year. Therefore, the calculations have to be done by sex, and merged to give the overall yield and biomass per recruit.

Recommended levels of fishing mortality may be F0.1 or FSPR35%, both taken as proxies for F_{MSY}. F_{MAX} is also considered, and would represent F_{MSY} if it can be assured that the recruitment is not reduced at this mortality. The choice of F_{MSY} proxy is selected for each functional unit independently according to the perception of stock resilience, factors affecting recruitment, population density, knowledge of biological parameters and the nature of the fishery (relative exploitation of the sexes and historical Harvest Rate vs. stock status).

The text below and Table 3.2.1 are cited from the Subarea VII *Nephrops* summary sheet 2012 to indicate how this has been practised.

MSY approach

There are no precautionary reference points defined for *Nephrops*. Under the new ICES MSY framework, exploitation rates likely to generate high long-term yield (and low probability of stock overfishing) have been explored and proposed for each functional unit. Owing to the way *Nephrops* are assessed, it is not possible to estimate F_{MSY} directly and hence proxies for F_{MSY} are determined. Three candidates for F_{MSY} are $F_{0.1}$, $F_{35\%SpR}$, and F_{MAX}. There may be strong differences in relative exploitation rates between the sexes for many stocks. To account for this, values for each of the candidates have been determined for males and females separately, and for the two sexes combined. The appropriate F_{MSY} candidate has been selected for each functional unit independently according to the perception of stock resilience, factors affecting recruitment, population density, knowledge of biological parameters, and the nature of the fishery (relative exploitation of the sexes and historical harvest rate vs. stock status).

A decision-making framework based on the table below was used in the selection of preliminary stock-specific F_{MSY} proxies. These may be modified following further data exploration and analysis. The combined sex F_{MSY} proxy should be considered appropriate provided that the resulting percentage of virgin spawner-per-recruit for males or females does not fall below 20%. In such a case a more conservative sex-specific F_{MSY} proxy should be chosen over the combined proxy.

Preliminary MSY $B_{trigger}$ reference points were proposed at the lowest abundance observed in the underwater TV (UWTV) survey. However, the time-series of surveys in Subarea VII are too short for that. For FU 15, where a longer series of survey trawl cpue was available; this was used to estimate a preliminary MSY $B_{trigger}$.

Table 3.2.2 shows the harvest rates corresponding to recently estimated F-reference points for some stocks. The rates that were used for advice are indicated.

3.3 Catch recommendations

Corresponding to the recommended fishing mortality is a harvest rate (HR). Multiplying the recommended HR by the assessed stock abundance in numbers provides a recommended number of removals. This may be converted to landings by subtracting dead discards and then multiplying by the expected mean weight in the landings. The survival rate of discarded *Nephrops* can be quite high, depending on fishing method and where the discarded animals reach the bottom. Hence, the total removals will be landings plus non-surviving discards.

Spawning–stock biomass is only used for estimating SSB reference points. Yearly recruitment estimates are not produced routinely, and no stock–recruitment relationships are derived. The size composition in the catches can give some indication of strong and weak year classes. The mean length of those individuals that are < 35 mm is sometimes used as a recruitment indicator. It can be considered, but should not be over-interpreted. For several stocks where long enough time-series of underwater TV (UWTV) survey abundance estimates are available in terms of stock numbers, the lowest abundance observed has been established as a proxy for MSY $B_{trigger}$ There are examples that the harvest rate has been reduced when this reference point has been exceeded. It should be noted that this reference point relates to measure of abundance that is specific to *Nephrops* due to the nature of the available abundance estimates. Hence, a better name might be feasible.

3.4 Stocks without TV-surveys

3.4.1 Classification according to criteria by WKLIFE II (ICES 2012)

WKLIFE II (ICES 2012) establishes procedures for generating advice for stocks with various shortcomings in the data. At the time of WK*NEPH*2013 the report from WKLIFEII is not finalized yet. However, the present draft was considered by the WK*NEPH*2013, leading to some proposals. According to the classification criteria as they stand, the *Nephrops* stocks cannot be regarded as a data-rich (Catergory 1), because the catch advice is derived by applying a harvest rate directly to a stock abundance estimate with no projection step. Furthermore, the abundance estimate comes directly from a survey rather than from an analytic assessment. The WG*NEPH*2013 considers that stocks where the standard procedure outlined here using TV surveys apply, should be handled in line with Category 1 stocks.

Nephrops stocks with no TV surveys do not fit clearly into any of the categories. They are indicated to be Category 4; stocks for which reliable catch data are available, are further indicated to be in Category 4.1.4 Data borrowing for sedentary species. For such stocks, WKLIFE II states that for the future, the catch recommendation should be set at a long-term average, with an 'uncertainty cap' or 'change limit' of ±20% when compared to recent catches. In the view of WK*NEPH*2013, this becomes overly precautionary for stocks that by all standards are lightly exploited, like FU 32. Some clarification of these guidelines appears to be needed. Moreover, a procedure for handling such stocks has been suggested (Section 3.4.2 below), which applies when there is the kind of knowledge commonly available for *Nephrops* stocks even without regular UWTV surveys. This procedure has been applied to several FUs both in the Celtic Sea Ecoregion and in the North Sea. WK*NEPH*2013 would propose this kind of procedure when the data allow.

3.4.2 North Sea data-poor' procedure

See Section 7 and WGCSE 2012, Section 2.8.3.2.

This procedure requires knowledge or assumptions of the habitat area, the mean weights and discard rates. Information on habitat area can be obtained from sediment maps or preferably from VMS data. Having that, stock abundance in numbers becomes a function of density which can be calculated. A reasonable range of densities can be outlined, based on information from preliminary UWTV surveys or as a last resort from neighbouring FUs. Then for such a range of densities, the corresponding harvest rates can be tabulated for a range of catches. A tool to do this is available as a spreadsheet derived at WGNSSK 2012 ('FINAL version of Nep-IV nonTVstocks included in advice.xls'. The harvest rate corresponding to the current level of catches can now be derived.

This is a harvest rate corresponding to a presumed stable stock abundance. Hence, it should be derived from averages over a time period that is sufficient to represent an equilibrium. It can be compared with what is regarded as an acceptable harvest rate in other FUs, or if possible, with a harvest rate derived from yield-per-recruit analysis. If the average HR appears to be satisfactory by common standards (PA and MSY), it can be maintained, i.e. a stable catch at the historical mean can be advised. If not, the catches should be reduced (or can be increased if the stock appears to be very lightly exploited) to a level corresponding to an acceptable HR. If this leads to a substantial change in catch, the uncertainty cap may apply, restricting the annual change to 20%.

A regime with a constant catch is known to be risky, because a temporary reduction in stock productivity may lead into a vicious circle. For that reason a precautionary buffer can be applied, recommending future catches at e.g. 80% of the recent mean. When deciding on whether to apply a buffer the following may be taken into account:

- The uncertainty in the current HR vs. recommended HR, which includes uncertainties of density and area, as well as uncertainty about growth, natural mortality and selection in the fishery.
- The opportunities to monitor trends in stock abundance, which can include lpue, changes in length distributions, changes in the fraction of females with eggs, changes in the area covered by the fishery (VMS data) and probably others.
- If there has been a recent expansion of the fishery, the deliberations above may not be representative for the current state of the stock, since the perception of the stock abundance does not reflect the dynamics of the stock. Hence, the procedure outlined here should imply a relatively stable fishery. If the fishery is to expand, it should be either because there is clear evidence that the stock is very lightly exploited, or it should be done in small steps, allowing experience to be gained underway. Hence, the uncertainty cap (constraint on increase in catch from year to year) may apply.

3.5 Use of other data

In addition to the data indicated above, there will typically be other data collected. From the fishery, this will be catch and effort data, and length and weights in the catches. There may also be trawl survey data, where *Nephrops* are caught and recorded, typically as a by-product in surveys for wider purposes.

The length–weight data go into the standard procedure as weights at length and mean weights. Survey and cpue indices provide relative measures of stock abundance. Length distributions may provide some indication of recruitment. Although this information is not used directly in the assessment procedure, they are valuable as a 'safety net', with the potential to give early warnings if something goes wrong. Likewise, if alternative approaches become relevant, time-series of length distributions and of relative abundance measures will be needed.

Such indicators may be sufficient to provide warnings that the stock is being reduced, for example through changes in lpue or length distributions or reduction in profitable fishing grounds. In cases where an UWTV based is not available, and TACs are recommended based on historical mean catches, such monitoring may provide warnings to reduce the dangers of maintaining a fixed TAC. This may be worth considering as an alternative to routinely recommend a catch below the recent average.

3.6 Alternative approaches

The procedure based on UWTV surveys outlined above has emerged as the standard procedure for *Nephrops*. However, other approaches are possible, that may be considered as alternatives for the future or if UWTV surveys break down.

3.6.1 Analytic assessments

In the past, it was standard practice to use a suite of indicators for *Nephrops* stocks. For many stocks age-based assessment methods (typically XSA) were carried out after converting lengths to ages by slicing, and tuning with commercial lpue information. Such methods, although no longer recommended as a standard may become relevant if the UWTV surveys break down. Having a time-series of catches by length, one may also consider length based analytic assessments, using for example survey or lpue data for tuning. There is some development in that direction at present. The general experience with such methods is that they are problematic because of confounding of parameters (growth rates, mortalities, catchabilities). Therefore, the WK*NEPH*2013 at present would recommend developing TV-surveys if possible, rather than relying solely on the development of length-structured analytic methods.

3.6.2 Production models

Production models have been tried with limited success in the past, but may still be worth considering, at least in cases where other approaches are problematic.

3.7 Future developments

Alternative methods typically rely on time-series of catch data and supplementary information. In contrast, one major advantage of the procedure established as standard for *Nephrops* is that it can in principle be applied with only one year of data. Some of the key parameters would nevertheless improve as more years' observations become available, like the fishable area and correction factors. Such and other parameters should still be refined as more experience is obtained.

Some parameters have values that are poorly substantiated. In particular, this is the case with growth parameters and natural mortality. Better justified values would of course be welcome. The alternative approach to such sources of uncertainty, as well as to the uncertainty with regard to the assumption that the survey is an absolute measure, would be to further explore the impact through sensitivity testing. One should then attempt to identify a range of harvest rates that may be satisfactory from a precautionary and MSY perspective across a reasonable range of the uncertain factors.

Table 3.2.1. Suggested F-reference points, taken from the Subarea VII *Nephrops* summary sheet 2012.

		Burrow density (average burrow m^{-2})		
		Low	Medium	High
		< 0.3	0.3–0.8	>0.8
Observed harvest rate or landings compared to stock status	>F_{max}	$F_{35\%SpR}$	F_{max}	F_{max}
	F_{max}–$F_{0.1}$	$F_{0.1}$	$F_{35\%SpR}$	F_{max}
	< $F_{0.1}$	$F_{0.1}$	$F_{0.1}$	$F_{35\%SpR}$
	Unknown	$F_{0.1}$	$F_{35\%SpR}$	$F_{35\%SpR}$
Stock size estimates	Variable	$F_{0.1}$	$F_{0.1}$	$F_{35\%SpR}$
	Stable	$F_{0.1}$	$F_{35\%SpR}$	F_{max}
Knowledge of biological parameters	Poor	$F_{0.1}$	$F_{0.1}$	$F_{35\%SpR}$
	Good	$F_{35\%SpR}$	$F_{35\%SpR}$	F_{max}
Historical fishery	Stable spatially and temporally	$F_{35\%SpR}$	$F_{35\%SpR}$	F_{max}
	Sporadic	$F_{0.1}$	$F_{0.1}$	$F_{35\%SpR}$
	Developing	$F_{0.1}$	$F_{35\%SpR}$	$F_{35\%SpR}$

Table 3.2.2. Overview of yield-per-recruit reference points derived from length cohort analysis for some ICES *Nephrops* stocks. The F_{MSY} proxies are highlighted in bold.

Harvest ratios for different (combined sex) F_{MSY} proxies			
FU	$F_{0.1}$	F_{max}	$F_{35\%spr}$
3&4	5.6	**7.9***	10.6
6**	7.2	12.1	11.5
7	**10.3**	18.5	12.4
8	9.4	**16.3**	12.7
9	7.8	14.9	**11.8**
11	9.8	16.9	**13.3**
12	9.7	16.9	**13.1**
13	9.3	16.9	**13.1**
14	**9.8**	16.4	13.0
15	10.6	**17.1**	13.4
16	**5.0**	10.7	7.7
17	7.2	11.1	**10.5**
19	**7.5**	12.7	12.1
22	7.5	12.3	**10.9**

***F_{MAX} taken as $F_{35\%SPR}$ is unusually high and this may be related to the high discard rates in the fishery.**

****$F_{35\%SPR}$ for male is used 8.0%**

4 FU 16 Porcupine

4.1 Current assessment and issues with data and assessment

The first UWTV survey of FU16 was carried out in June 2012 (Lordan *et al*., 2012) and formed the basis of the management advice for 2013 using the usual ICES approach (ICES, 2012). The survey was reviewed by a special process setup by ACOM in October 2012. WK*NEPH* 2013 mainly focused on this new UWTV survey and data used to estimate the various parameters required in the ICES UWTV approach. WK*NEPH* also reviewed both new and old data available for this stock.

Prior to this UWTV survey the assessment and management advice was based on an analysis of trends and indicators derived from fishery data and Spanish Porcupine trawl survey (SpPGFS-WIBTS-Q4). This approach informed the perception of general stock development but did not provide an objective way of providing landings/catch advice. With the development of the data limited approach WGCSE 2012 explored DCAC and the *Nephrops* data-limited approach (but without knowledge of mean burrow density (ICES, 2012)). Historically XSA was also applied to this stock by WG*NEPH* 2003 (ICES, 2003).

4.2 Compilation of available data; revisions in particular, incl. new data

4.2.1 Catch and landings data, incl. selection at length

Length compositions of annual landings are available from Spain (1986–2009), France (1995–2007) and Ireland (1995–2005 and 2008–2012). Sampling intensity in Spain was extremely low in 2008 and 2009 (two and five samples) and no sampling data has been made available since 2010. There has been no sampling in France since 2008 due to low landings.

No sampling was possible in 2006 and 2007 for Ireland due to the withdrawal of co-operation with scientific sampling programmes by the fishing industry. Sampling in Ireland resumed in 2008 but sampling levels were low initially due to problems in accessing frozen graded landings. Since 2010 and 2011 landings length distributions have be reconstructed using data on the size distribution and volumes of each frozen grade landed. In 2012 the Irish industry provided grade data for approximately 45% of the total landings.

Sampling of *Nephrops* in this area is hampered by several factors:

- The remote nature of the fishery.
- Trips are long duration (normally >12 days) sometimes fishing in multiple areas.
- An increasing proportion of the landings are landed frozen and graded at sea making access to samples problematic.
- There is reluctance from fishermen and processors to allow sampling of landings due to high value of the larger *Nephrops* and the risk of damage to individuals during sampling.

Sampling intensity in the period 2006–2009 was insufficient to get robust and accurate length structure data of the landing. Despite the low sampling intensity in recent years, the trends in indicators such as length and sex ratio are consistent across data from the different countries and in the survey.

Reconstructing size structure for graded landings

Typically Irish vessels land *Nephrops* from the Porcupine Bank in 7–8 commercial size grades based on counts of numbers of individuals per kg. An example is of the sampled length distributions in each grade and given in Table 4.2.1. Since 2011 WGCSE have been reconstructing the size distribution of the landings based on sampling of the commercial size grades and raising the sampled weight to the landed weight of each commercial size grade. Information on the proportion of each size grade in their annual landings is provided by the fishing industry.

Table 4.2.1. The length–frequency distributions observed in the different commercial size grades sampled on vessels fishing the Porcupine Bank in 2012.

Row La	0-5	5-10	10-15	15-20	20-30	30-40	40-50	50-60
25						1		
26						1	6	
27							10	
28						4	16	
29						4	32	3
30					2	6	74	3
31						31	100	7
32					4	55	141	29
33					9	102	138	49
34					14	146	80	79
35				1	49	154	54	58
36					73	148	47	20
37				3	142	107	49	12
38				13	151	87	51	
39				30	165	66	25	
40			2	55	161	55	10	
41			4	104	145	28		
42		1	15	132	112	11	1	
43			30	175	73	2		
44		2	75	143	49	1		
45		2	97	144	34	1		
46		4	145	78	24			
47		25	146	45	19			
48		30	129	21	11			
49		54	76	9	4			
50		78	63	2	2			
51		89	38	1	2			
52		109	20		1			
53		105	16					
54	1	108	7					
55	1	70	2					
56	5	71						
57	4	44						
58	19	31						
59	41	20						
60	55	12						
61	64	2						
62	56	5						
63	55	3						
64	54	3						
65	43	1						
66	40							
67	31							
68	25							
69	18							
70	18							
71	15							
72	7							
73	3							
74	1							
75	1							
76	3							
77	1							
78	1							

Aspects of accuracy, precision and bias of this method was considered at WK*NEPH* keeping in mind that more data are becoming available each year and experience with this method is developing. In the UWTV based approach the main variable of interest for the estimation of harvest ratio and provision of landings advice the mean weight in the landings (discards are estimated to be negligible currently for this stock). Estimation of this variable is sensitive to: i) the variability of mean weight within each grade and ii) the variability of the composition of the grades. In addition, various indicators based on the length distributions of the landings are used to monitor this stock.

For the purpose of this analysis all lengths were converted to weights using a length–weight relationship with parameters a = 0.00009 and b = 3.550. Grades are defined by the number of individuals per kg (e.g. the grade '5–10' has between five and ten individuals per kg). This means there is an absolute minimum mean weight for individuals in each grade (1000 g divided by the maximum number of individuals allowed in the grade; Table 4.2.4 and Figure 4.2.1). The largest grade (1–5) will rarely have less than three individuals because *Nephrops* of more than 500 g are extremely rare, so for this size class the maximum mean weight will not be 1000 g but more likely 333 g. Even so, there is potential for considerable variability of the grades with large prawns. Grades with small individuals often seem to have larger mean weights than expected which may indicate that the price difference between these grades is so low it is not cost-effective to sort them into the highest possible grade (Figure 4.2.1).

Variability of mean weight within each grade

Table 4.2.1 shows that the number of samples available is too low for a robust bootstrapping approach. However by making assumptions on the distribution of the mean weight within each grade, we can simulate this distribution and calculate the variability. We calculated the mean and standard deviation of the mean weight in each grade (Table 4.2.2) and simulated sampling these grades by taking samples from a random normal distribution using the mean and standard deviation from Table 4.2.2. The mean over the grades was weighted by the proportion of each grade in the overall landings. In this way an estimate of the mean weight of the individuals in the catch was obtained for 1000 iterations. Each iteration simulates taking one sample of each grade. For 2012 the overall mean weight in the landings estimate was 50.5 g with a standard deviation of 4.9%. The expected standard error is therefore $4.9\%/\sqrt{n}$ where n is the number of samples taken. In 2012 the 95% confidence interval on the mean would be in the order of +/-5%. This implies the method gives a relatively precise estimate of mean weight.

Variability of the composition of the grades

The estimated mean weight composition of the grades potentially an important source of variability and bias (Figure 4.2.2). We assumed that the composition of the grades followed a multinomial distribution. The variability of this distribution decreases with the number of trials so we chose a number of trials (N=100) that appeared to result in a variability that matched the spread of the samples. In future if the industry provide individual records of the grade composition of the landings it should be possible to explore variability and bias arising from this. In the meantime the best approach is to encourage the industry to accurately provide this information on an ongoing basis to scientific agencies assessing this stock.

Table 4.2.1. The number of samples available by grade and year. 'Sample' can mean combined data for a co-op in a year, combined data for a vessel in a year or a sample from a survey on a commercial vessel.

	Grade (Numbers per kg)						
Year	0–5	5–10	10–15	15–20	20–30	30–40	40–50
2010	1	3	2	1	1	1	0
2011	7	2	3	3	2	5	3
2012	4	7	5	5	5	5	4
Total	12	12	10	9	8	11	7

Table 4.2.2. The mean weight of individuals (g) in each grade and their standard deviation (sd). The expected minimum and maximum mean weights are also given.

Grade	mean	Sd	Min	max
1–5	261	30.3	200	1000
5–10	137	17.1	100	200
10–15	85	5.1	67	100
15–20	64	4.5	50	67
20–30	47	8.6	33	50
30–40	33	5.9	25	33
40–50	24	5.9	20	25

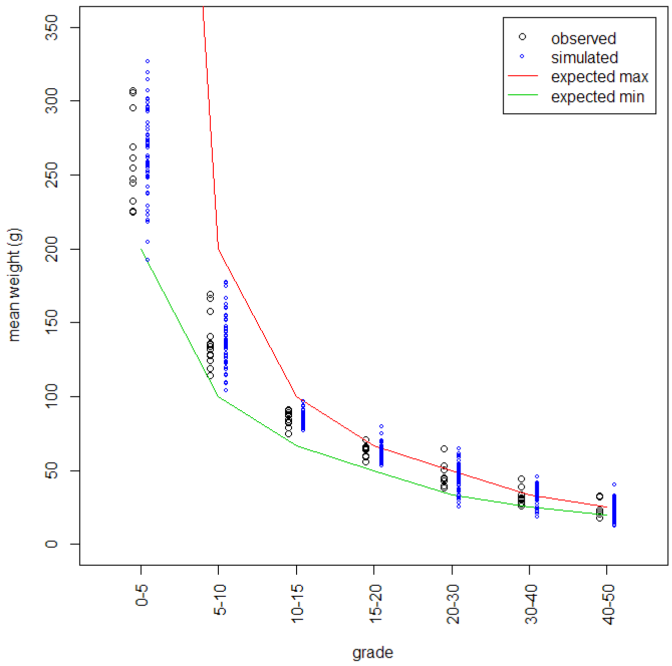

Figure 4.2.1. Observed and expected range of mean weights of individuals in each grade, the first 50 simulated mean weights are shown in blue.

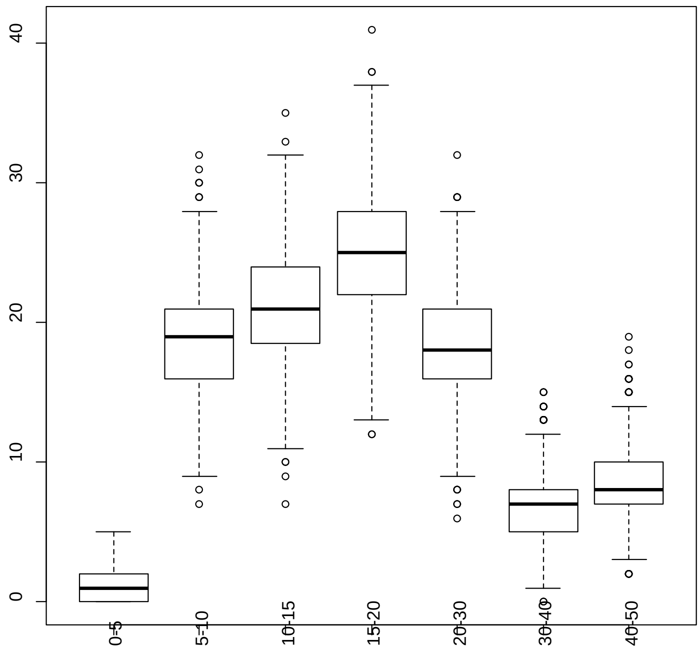

Figure 4.2.2. Variability of the composition of the grades.

WK*NEPH* concluded that the approach used to reconstruct the mean weight in the landings and other stock indicators using the commercial size grades is relatively robust and a practical alternative to other sampling approaches given the nature of this fishery. **WK*NEPH* recommend that the fishing industry continue to provide grade landings data on an ongoing basis and allow sufficient sampling of graded landings across vessels operating in the fishery.**

4.2.2 Biological data (Growth, maturity, natural mortality)

Growth

The scientific basis for growth parameters for this stock is very weak (Table 4.2.1). It seems that the current growth parameters were first established in 1990 (slightly different values appear in the 1989 report). These parameters were adapted based on expert judgement and by analogy with other stocks together with maximum size observed in the landings (ICES, 1990).

Other von Bertalanffy parameter estimates were derived by fitting normal distributions with Multifan as part of an EC project entitled "Ageing of *Nephrops* in western waters DGXIV 1995/006 (Thompson *et al.*, 2000). That analysis used Spanish port sampling data for April and November collected between 1986–1997. The Multifan model was fitted with fixed standard deviation constraint (Table 4.2.2). They also looked at disaggregating the data into two time periods 1986–1992 and 1993–1997. Interestingly this produced quite similar mean length-at-age for the main cohorts but with quite different k and Linf estimates (highlighting the high correlation between Linf and K). The main conclusion of that work was that Multifan could estimate growth parameters with acceptable accuracy, where the growth of a cohort with a clearly identifiable length-mode could be followed for an adequate period before the mode became lost. This is seldom the case with *Nephrops* in real world situations where growth is variable due to density, habitat and other factors (Johnson *et al*., 2013).

WK*NEPH* investigated the growth of the cohort first observed in September 2009 in catches made on the SpPGFS-WIBTS-Q4 between 2009–2012. Normal distributions were fitted to the observed length distributions using the mixdist package in R (Version: 0.5-4, Date: 2011-10-18). Various different parameter setting and constraints were explored. Given that the observed length distributions appear to be dominated by a single large cohort the starting parameters were set accordingly. The resulting fits are shown in Figure 4.2.1. These are not entirely satisfactory since growth appears well tacked between 2009 and 2010 with modes at 27.0 mm and 33.7 mm. The main mode fitted in 2011 at 35.5 mm appears out of line with previous years' observations. The main mode is estimated at 39.6 in 2012. Plotting the fitted mode estimates on the growth curves derived from the parameters in Table 4.2.1 illustrates the problem (Figure 4.2.2). The cohort fits are close to the existing growth curve in 2009 and 2010 but the 2011 and 2012 cohorts are closer to the Multifan estimates of Thompson *et al*. (2000).

WK*NEPH* concluded that currently there is no strong basis to revise the growth parameters currently in use for this stock (as used by Lordan *et al.*, 2012 to derive F_{MSY} harvest ratios). Some sensitivity testing to alternative growth parameters should be carried out when fitting the LCAs to derive inputs to the per recruit analysis. WK*NEPH* recommend that dedicated research into direct determination of age should be carried out across *Nephrops* socks since recent investigations in shrimps, crabs, and lobsters yield very promising results (Kilada *et al*., 2012). A combination of experimental direct age observations and cohort fitting to length distributions is likely to yield a better understanding of *Nephrops* growth and age composition at a population level.

Table 4.2.1. Available growth parameters for Porcupine *Nephrops*.

Sex & Maturity	K	Linf	Estimation Methodology	Source
Males	0.14	75	Based on values in other areas	First used by ICES. 1990 and used by various ICES Working Groups WGNEPH, WGHMM since.
Immature Females	0.14	75	Based on maximum sizes observed in samples (ICES. 1990)	
Mature Females	0.14	60	Based on maximum sizes observed in samples	
Males	0.18	70.7	Multifan	Thompson *et al*., 2000

Table 4.2.2. Mean lengths-at-age and von Bertalanffy growth parameters for the commercial Porcupine Bank *Nephrops norvegicus* population calculated by Multifan (Thompson *et al.*, 2000). The total dataset (1986–1997) has been divided into two separate datasets, 1986–1992 and 1993–1997.

DataSets (years)	von B. Parameters		Multifan mean length-at-age (mm)								
	K	L_∞	1	2	3	4	5	6	7	8	9
1986–1992 January	0.33	55.6	13.39	<u>25.30</u>	<u>33.84</u>	<u>39.98</u>	<u>44.38</u>	47.53	–	–	–
1993–1997 November	0.21	68.7	15.67	<u>25.66</u>	<u>33.77</u>	<u>40.34</u>	<u>45.68</u>	50.05	53.53	56.39	58.70
1986–1997 November	0.18	70.7	19.24	<u>27.70</u>	<u>34.77</u>	<u>40.68</u>	<u>45.61</u>	49.74	53.18	56.06	58.47

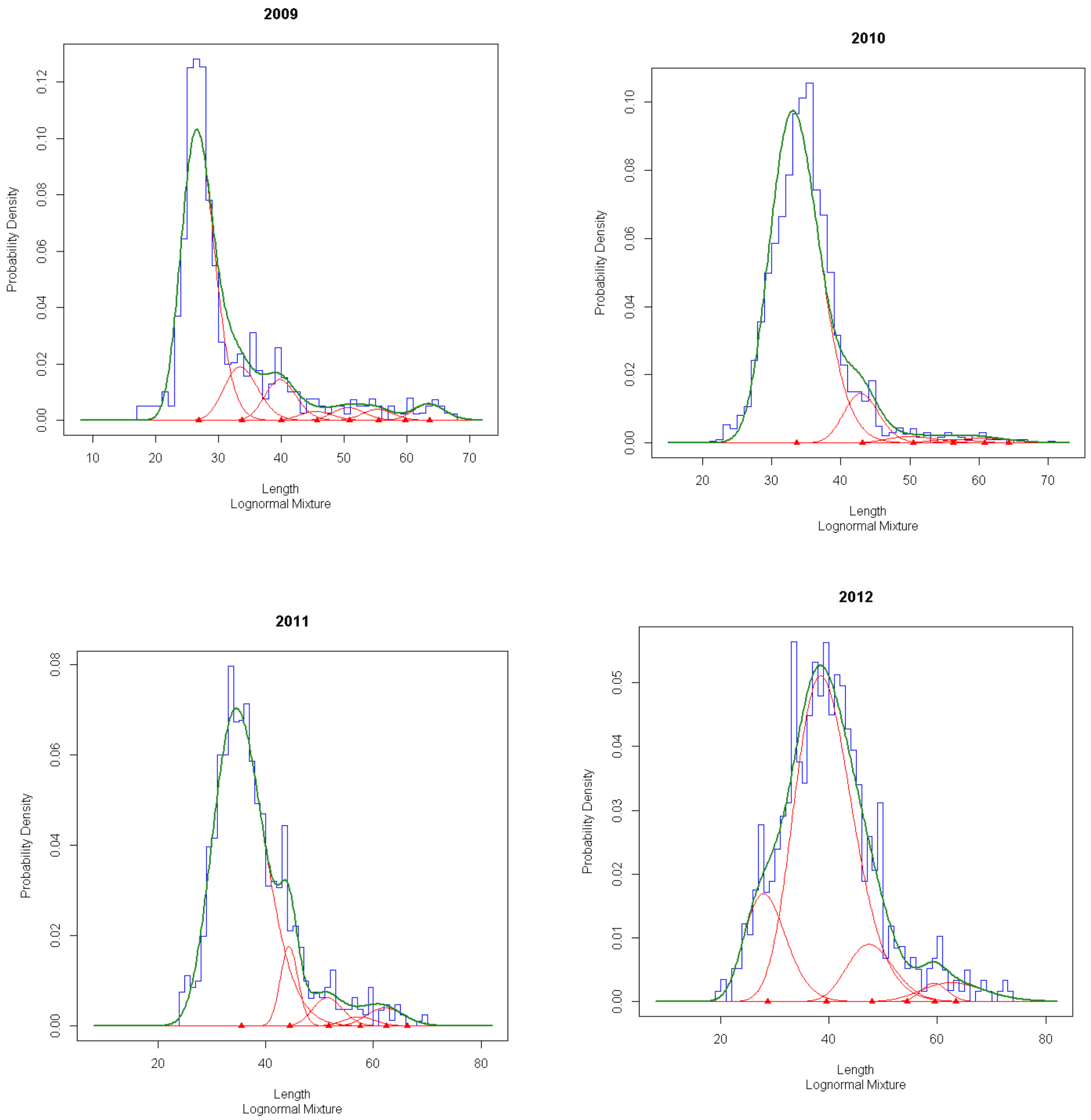

Figure 4.2.1. Fitting of normal mixture distributions to male length–frequency distributions from the Spanish Porcupine survey (SpPGFS-WIBTS-Q4) between 2009–2012.

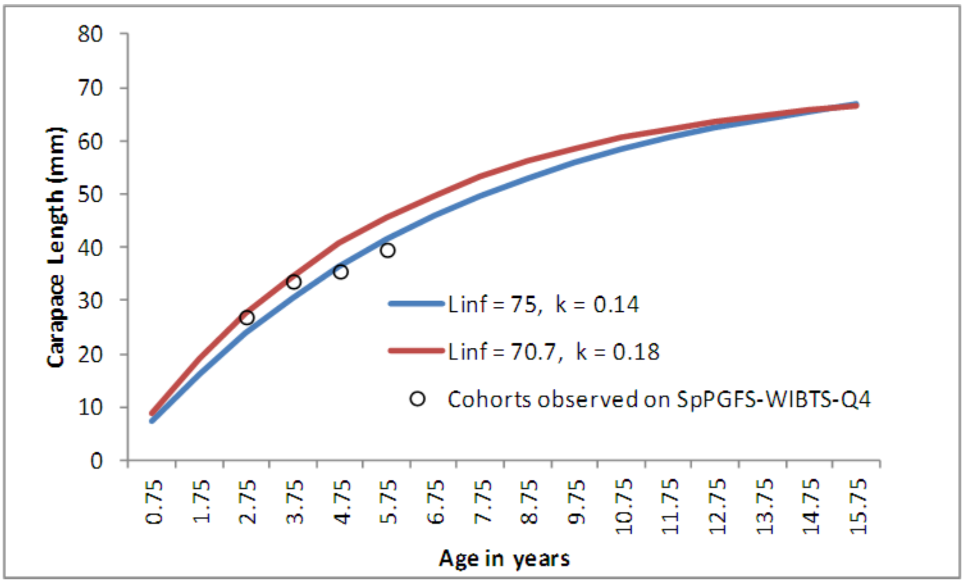

Figure 4.2.2. Plot of possible growth curves for FU16 *Nephrops* with main cohort observed on the Spanish survey between 2009–2012 overlaid.

Maturity

The published estimates of L_{50} (length at 50% maturity) for the Porcupine Bank range from 26.4 mm to around 30 mm (González Herraiz and Fariña, 2005; Stokes and Lordan, 2011). WK*NEPH* 2013 considered the various methodologies and criteria used to estimate maturity in *Nephrops* based on information provided in WD 2 (González Herraiz *et al.*). Parameter estimates for fitted logistic regressions to visual maturity data on female *Nephrops* collected on the IFSRP trawl surveys on the Porcupine Bank in 2010–2012 was also available to WK*NEPH* (Table 4.2.3).

Table 4.2.3. Parameter estimates for fitted logistic regressions to visual female maturity data collected on the IFSRP trawl surveys on the Porcupine Bank in 2010–2012.

Year	Intercept	Slope	L_{50}	95 percentiles on L_{50}		Sample Number
2010	-13.5621747	0.4307454	31.48536	31.00011	31.94627	4655
2011	-16.7412050	0.5395481	31.0282	30.9303	31.2289	11 262
2012	-20.9397141	0.7258373	28.84905	28.61801	29.05573	8100

This analysis highlights that the size-at-maturity estimates can be quite variable possibly due to spatial and temporal factors as well as sampling effects. Female maturity has only been considered as data and a robust methodology to estimate male maturity was not available. WK*NEPH* concluded that a weighted average of size-at-maturity estimates based on female samples collected on the SpPGFS-WIBTS-Q4 survey in the years 2001–2004, 2009 and 2012 was the most appropriate to this stock. This gives a size at maturity of 28.7 mm CL. **WK*NEPH* recommends that monitoring of maturity and presence of spermatophores be continued on this survey and that the parameter estimate be revised as necessary.**

Sex Ratio

Previous *Nephrops* working groups have highlighted stability in sex ratio as an important indicator for *Nephrops* stocks. The landings and fishery-independent survey catches show a dramatic switch in the sex ratio for this stock with larger proportions of females in the catches between 2007 and 2009. **WK*NEPH* recommend that sex ratio indicators be updated and reviewed annually.**

Sperm limitation

Fishing directed only at large males can skew the population sex ratio, promote mating of less fecund males, reduces opportunity for mate choice for females or in extreme cases increase the risk of sperm limitation. Sperm limitation is known to occur (or be at risk of occurring) in a variety of decapod crustaceans (e.g. Sainte-Marie *et al.*, 2008; Gosselin *et al.*, 2005). Recent indicators from the Porcupine *Nephrops* fishery are consistent with a stock which may have suffered sperm limitation between 2007 and 2009 when stock abundance was thought to have been very low.

Mature female *Nephrops* on the Porcupine Bank probably only moult once a year. The moult occurs shortly after hatching of eggs in April or May. There is a 24 hour period after moulting when the male *Nephrops* can mate with the female according to Farmer (1974). If there are insufficient males of appropriate size in the population to mate with the recently moulted females this can result in be the partial or complete loss of their egg clutches. Consequently females change behaviour concentrating on feeding and growth instead of reproduction.

WK*NEPH* 2013 reexamined the available scientific data on proportions of females mated as observed on the Spanish survey (González Herraiz *et al.*, WD 2). These results showed high proportions of unmated females and a high L_{50} for mated females in catches in 2009 (Figure 4.2.3). Catches of females in 2007 and 2008 were too low to fit curves too. In 2012, there were also several observations of females above the size-at-maturity which were not mated. Simulations were also carried out to investigate the densities at which sperm limitation may become an issue given a range of plausible ranges of stock density, sex ratios, search radii (Bell, WD 1). The conclusion of that analysis was that at the densities recently observed on the Porcupine Bank that sperm limitation was a real possibility for this stock.

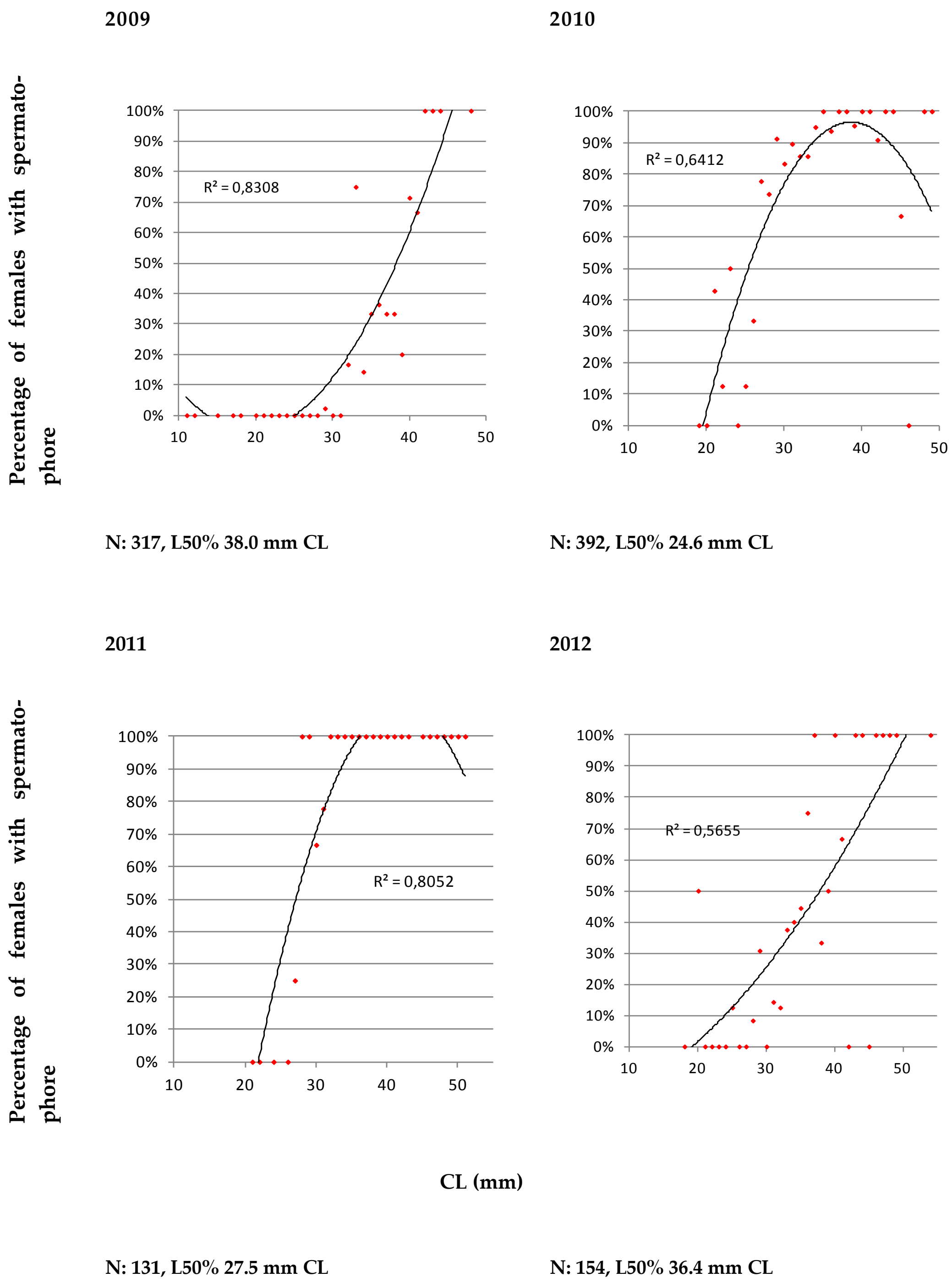

Figure 4.2.3. Percentage of females with spermatophore by length class (mm CL). With polinomic trend lines. 2009–2012 Spanish Porcupine Survey data.

WK*NEPH* concluded that there was some evidence of sperm limitation in this stock and recommend that this should be monitored in future.

Natural Mortality

The scientific basis for natural mortality estimates in this and other *Nephrops* stocks is weak. Known predators of *Nephrops* on the Porcupine Bank include *Lophius* sp., *Chimeara* sp. and possibly other elasmobranch species. It is not possible or practical to estimate the level of natural mortality or predations for this stock.

A natural mortality rate of 0.2 was assumed for all age classes and both sexes. The male M is lower than that typically used for most other *Nephrops* stocks (normally 0.3). The accuracy of these assumptions is unknown but some sensitive testing on the impact to F reference points has been carried out (Lordan *et al*., 2012). The conclusion was that $F_{0.1}$ was not overly sensitive to the M assumption.

Exploration of Length-weight

The source and accuracy of historic length–weight parameters for this stock is also questionable. At WK*NEPH* new length–weight parameters (given below) were estimated based on Spanish sampling of fresh landings carried out between October 2001–January 2003. No alternative length–weight data were available to WK*NEPH*.

	A	B	Size range	Sample Size
Females	0.0009	2.9131	25.4–59.5	263
Males	0.0002	3.2736	29.8–69.7	372

When these parameters were applied to the frozen graded landings data it became apparent that the estimated mean weights did not fall within the bounds of all the grade categories. There was a bias particularly for the larger grade categories.

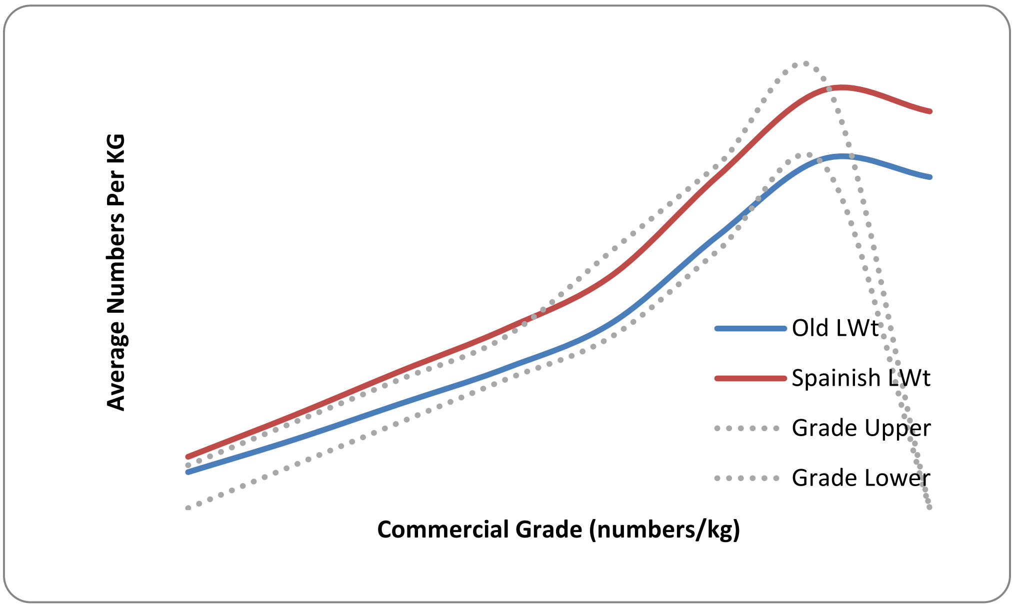

Figure 4.2.4. Average numbers per market sized grade using different length–weight parameters available for FU16 *Nephrops*.

WK*NEPH* decided to retain the old length–weight parameters for these stocks until better estimates based on robust sampling become available. **WK*NEPH* recommends that sampling of length–weight be carried out and that the length–weight parameters used for this stock be update as necessary based on the results of this sampling.**

4.2.3 Survey data

The longest time-series of fishery-independent source of data is from the Spanish Porcupine trawl survey 2001–current year (SpPGFS-WIBTS-Q4). The gear used on this survey is the Baca trawl gear. This survey is carried out in September when *Nephrops* catchability is quite low, particularly of adults. Further information on this survey is provided in the IBTS report (ICES, 2009) and in previous IBTS reports.

This survey provides an index of recruitment and cpue in numbers and kg per hour for this stock. WK*NEPH* recommends that this index is presented and discussed annually in the assessment for this stock.

4.2.4 Commercial data (lpue etc.)

The time-series of French, Irish and Spanish lpue and effort trends have routinely been presented as part of the background data for this stock (see previous WGCSE reports and table below). French and Irish data have been presented as effort in hours fishing and lpue in kg/hr thresholds have been used to define '*Nephrops* targeting'. French effort has declined to less than 4000 hours since 2008 and lpue estimates can no longer be considered reliable.

The available effort time-series are summarized below:

Country	First year of effort data	Units	Comment
France	1983	Hours	For trips where *Nephrops* constituted 10% of the landed value
Ireland	2005	Hours	For trips where *Nephrops* constituted 30% of the landings in weight
Spain	1971	ay*BHP/100 (x1000)	

The derivation and standardization of Irish lpue data were explained and explored in detail by Gerritsen and Lordan (2011). This work showed significant changes in fishing pattern for the Irish *Nephrops* directed vessels on the Porcupine Bank both in space and time. Vessels now appear to target larger more valuable *Nephrops* which are typically caught in areas or at times with lower lpue. Various different lpue derivation and GLM standardization methodologies gave broadly similar trends (Figures 4.2.4 and 4.2.5). Lpue was highest in the start of the series declining to the lowest values between 2004–2008; with a slight upturn towards the end of the series. Gerritsen and Lordan (2011) concluded that the lpue trend may not fully reflect stock abundance given the underlying changes in targeting practices and it was not possible to standardize for this sufficiently.

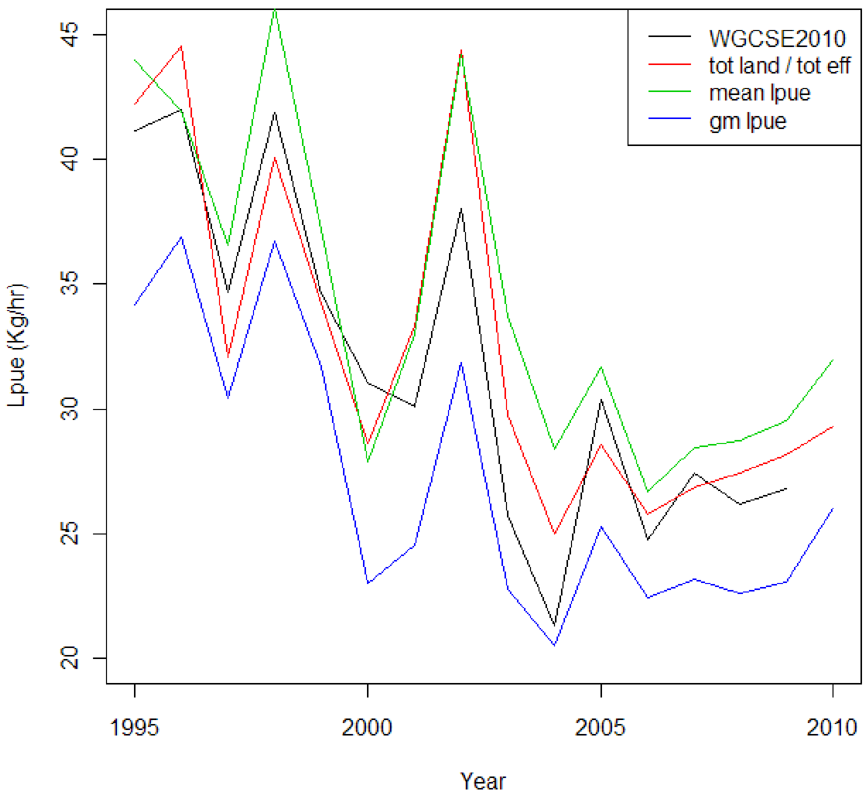

Figure 4.2.5. The lpue used by WGCSE 2010 and three other methods of estimating lpue: 1) the total annual landings divided by the total annual effort; 2) the mean lpue over all vessel-days; 3) the geometric mean lpue over all vessel days.

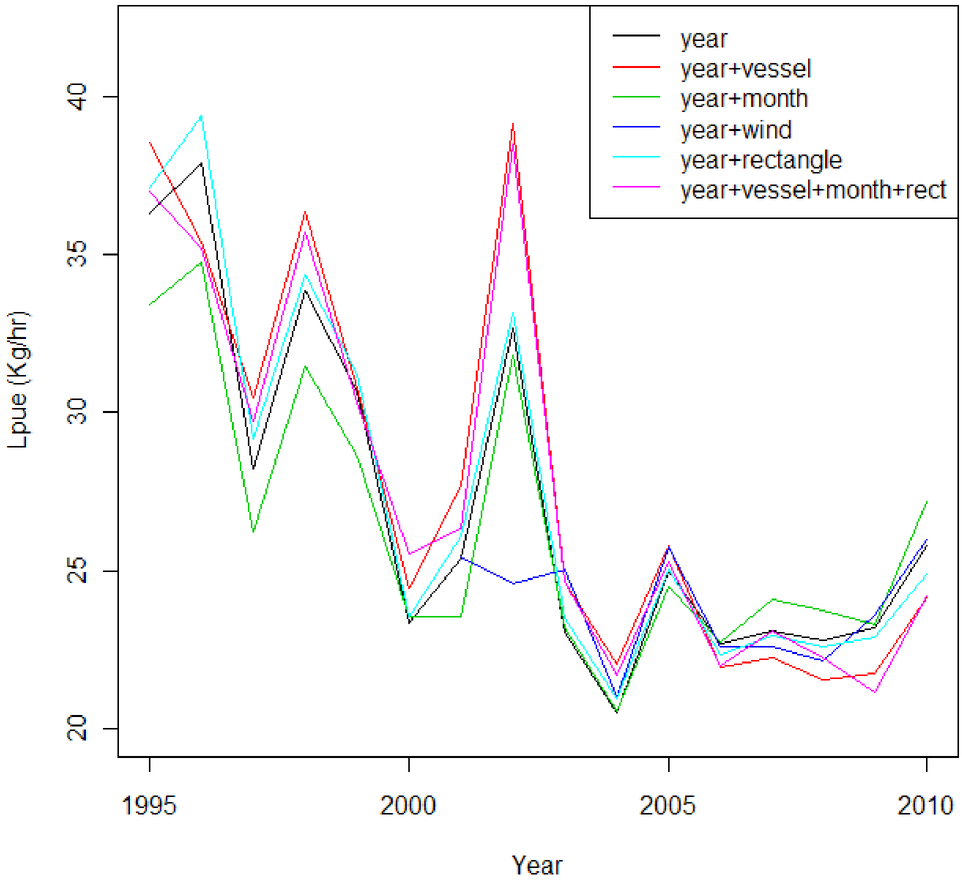

Figure 4.2.6. Standardized lpue indices based on six different models which all included year as an explanatory variable as well as vessel, month, windspeed and/or ices rectangle. No interactions were fitted.

The Spanish data were presented as a vessel power corrected index in fishing day*BHP/100 (x1000) and lpue as kg/day*BHP/100. Some work was carried out at and prior to WK*NEPH* to estimate the Spanish effort and lpue in hours and kg/hr (fishing days was converted to hours by multiplying by 14 based on observations that the mean fishing time was 14 hours/day). Before 2011 landings and the effort provided by Spain to the WG were IEO estimates. These estimates were made with aggregated sales notes. In the case of FU16 until 2010 both landings and effort was really for all Subarea VII; since the Porcupine Bank could not be selected alone (note the vast majority of the VII landings by Spain are from FU16). Since 2012, effort and lpue was provided only for the rectangles of FU16 based on official logbooks so the two time-series are no longer comparable.

More recently it has become possible to estimate effort within the *Nephrops* ground on the Porcupine Bank using VMS data (using the methods described in Gerritsen and Lordan, 2011). WGCSE has been reporting VMS effort and using it to quality check logbook data (ICES, 2012). In the future linking VMS and logbook information should provide higher spatial and temporal resolution effort and lpue time-series for this area.

WK*NEPH* concluded that effort and lpue series should be maintained in the WGCSE report for information purposes. Any inferences about changes in stock abundance from these data should take account of the quality and bias concerns raised above.

4.2.5 Other indicators (length distributions and others)

It is difficult to extract other useful signals in the length–frequency distributions plot, so for male *Nephrops* three simple indicators are normally calculated. These are as follows:

- A recruitment proxy (% of males <32 mm CL)
- The percentage of larger individuals (>50 mm CL) in the sampled landings.
- An exploitation proxy was also calculated using the slope of ln(CL) vs. ln(Numbers) between 41–56 mm CL i.e. the slope of downward limb on the right-hand side of the length–frequency distribution.

WK*NEPH* concluded that these indicators remain appropriate and recommend that these should be updated in each assessment of this stock.

4.2.6 Industry/stakeholder data inputs

An Irish Fisheries Science Research Partnership (IFSRP) survey was developed in collaboration the Irish fishing industry to obtain data from the closed area in 2010–2012. Details of the design and methodology are presented in Stokes and Lordan (2011). The survey uses both commercial gear (Comm) and a baca trawl similar to the SpPGFS-WIBTS-Q4. Bubble plots of the cpue on this survey shown in Figure 4.2.7.

WK*NEPH* concluded that the IFSRP trawl survey is too short (with changes in coverage, gears and vessels) to draw an inference about cpue changes reflecting changing stock abundance. The survey does however provide very useful data on population structure across the ground as well as data on grade structure and maturity-at-length (see Table 4.2.3.). There is a significant difference in catch rates and size structure in the catches between the IFSRP survey in July and the SpPGFS-WIBTS-Q4 in September using as similar net (Figure 4.2.8). This is likely to be related to behaviour of *Nephrops* where the adults are more active on the surface in July compared with September.

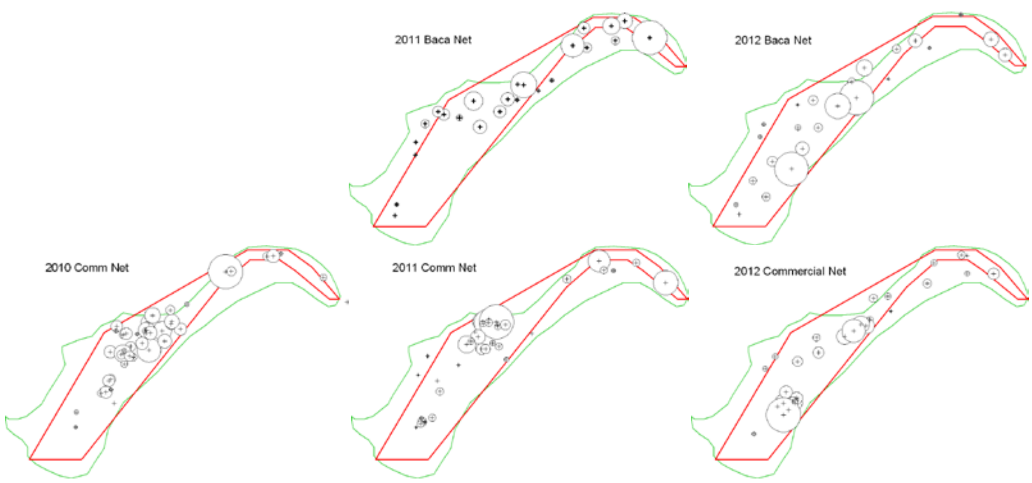

Figure 4.2.7. Bubble plots of catch rates in kg/hour fished for IFSRP surveys on the Porcupine Bank (FU16) between 2010–2012.

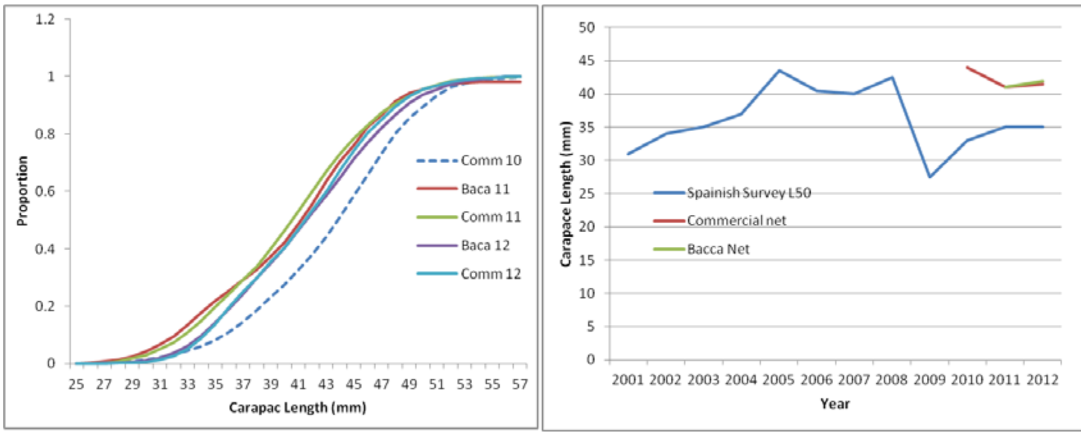

Figure 4.2.8. Cumulative length distribution of catches on the IFSRP surveys by year and gear (left panel) and time-series of the L_{50} or modal length in the catches for the IFSRP surveys and Spanish survey (SpPGFS-WIBTS-Q4).

4.2.7 Environmental data

Various datasets were available to WK*NEPH* on the physical environment. These included direct observations on ocean conditions and weather from data buoys (http://www.marine.ie/home/publicationsdata/data/buoys/) as well as modelled datasets such as mean annual kinetic based on bottom current velocities from a ROMS model.

(http://www.marine.ie/home/services/operational/oceanography/OceanForecast.htm) Substrate datasets from the Irish National Seabed Survey (INSS) were collated and merged thanks to the MeshAtlantic project (http://www.meshatlantic.eu/).

4.3 Stock identity, distribution and migration issues

The *Nephrops* stock on the Porcupine Bank is distributed on a fairly continuous mud patch in relatively deep waters 260–570 m. The boundary used by Lordan *et al*. (2012) to delineate the edge of the ground was based on VMS data of fishing activity between 2006–2011for Irish vessels targeting *Nephrops* (where >30% of daily operational landings was reported to be *Nephrops* using the methods described in Gerritsen and Lordan, 2011). WK*NEPH* concluded that the ground boundary is fairly well delineated and corresponds well to the fished stock distribution. The actual distribution of *Nephrops* on the bank is likely to be slightly wider since Irish activity may not cover all the area the species occurs and there are known to be some catches on the SpPGFS-WIBTS-Q4 beyond the current boundary. WK*NEPH* concluded that the current boundary as defined in the updated stock annex be used as the basis for stock abundance calculations and that the boundary should be reviewed and new information becomes available.

Migration is not generally considered to occur in territorial and aggressive *Nephrops*. However, given the low stock size in the Porcupine Bank there may well be scope for migration to occur. The changing distribution of cpue observed between 2009 and 2010 could be evidence of a migration of the stock outwards from a centralized area of high recruitment. It is also interesting to observe that differences in size across the ground are not as evident in recent years since the 2009 recruitment. UWTV data suggest that average burrow densities across most of the ground are relatively homogeneous but within transect burrows are clumped in their distribution relative to grounds with higher density (Lordan *et al*., 2012).

4.4 Influence of the fishery on the stock dynamic

Given the general decline in long-term lpue and trends in the various stock indicators it is clear that the fishery has had some influence on the stock dynamics.

4.5 Influence of environmental drivers on the stock dynamic

The formation of a cyclic gyre known as a Taylor Column structure has been observed over the Porcupine Bank previously (White *et al*., 1998) but its occurrence is not annual and the strength of the gyre, linked to windstressings and deep-water upwellings is highly variable. This gyre does provide an important mechanism for the retention of pelagic eggs and larvae of the various marine species spawning in the area. (Mohn, *et al*., 2002). The formation of cyclical gyres over *Nephrops* mud-patches have been postulated as being a key factor in the recruitment dynamics for this species but the exact role, if any, of the Taylor column in Porcupine *Nephrops* larval retention is yet well understood.

González Herraiz *et al*. (2009) linked the North Atlantic Oscillation index "NAO" to cpue cycles using dynamic ARMA model whereby cpue is positively related to sex ratio lagged by eight years and negatively related to the NAO index from six and a half years before. The underlying processes, including trophic changes and recruitment process were discussed but not explored further.

The main environmental driver considered by WK*NEPH* was the hydrodynamic conditions involved in the dispersal and retention of *Nephrops* larvae over the Porcupine Bank (O'Sullivan and Lordan, WD7). After a period of weak recruitment between 2003 and 2008 a good recruitment was observed in 2009 survey data. These are most likely associated with unfavourable and favourable environmental conditions respectively. Although significant effort was put into the development, parameterization and evaluation of various partial tracking scenarios in WD 7 the work remains too preliminary to draw to many firm conclusions. The results do show that vertical distribution of the larvae is a critical to larval retention. **WK*NEPH* recommend that this work be continued in future given that this stock undoubtedly experience variable recruitment and is at risk of weak recruitment for periods of several years.**

4.6 Role of multispecies interactions

4.6.1 Trophic interactions

Trophic and multispecies interactions were not discussed at WK*NEPH* 2013.

4.6.2 Fishery interactions

4.7 Impacts of the fishery on the ecosystem

The frequency of trawl disturbance on *Nephrops* grounds was explored in detail in by Gerritsen and Lordan in WD 6. Quantify the frequency of *Nephrops* trawling impact on the seabed is important step to assess direct and indirect effects of trawling *Nephrops* on vulnerable species and habitats. OSPAR have designated seapens and burrowing megafauna communities as threatened and/or declining habitats in the waters around Ireland (OSPAR, 2010). The seapen species *Funiculina quadrangularis* is undoubtedly sensitive to trawling and has been observed at low numbers during the 2012 UWTV survey (Lordan, unpublished data). In a review report Power and Lordan (2012) found that the distribution of groundfish survey catches of

F. quadrangularis did not overlap with the main *Nephrops* fishing grounds suggesting that the distribution of *F. quadrangularis* is not necessarily coincident with *Nephrops*.

The majority of the Porcupine Bank is fished at least once annually based on the methods described in Gerritsen *et al*. (2013). Figure 4.7.1 shows the mean number of times each grid cell in the area was impacted by fishing gear. In the northeastern side of the grounds it is not uncommon for a location to be impacted five times or more per year. Table 4.7.1 shows that 44–64% of the area is impacted at least once per year by fishing gear; 8–28% is impacted at least twice; 2–10% at least five times and 0–1% at least ten times per year.

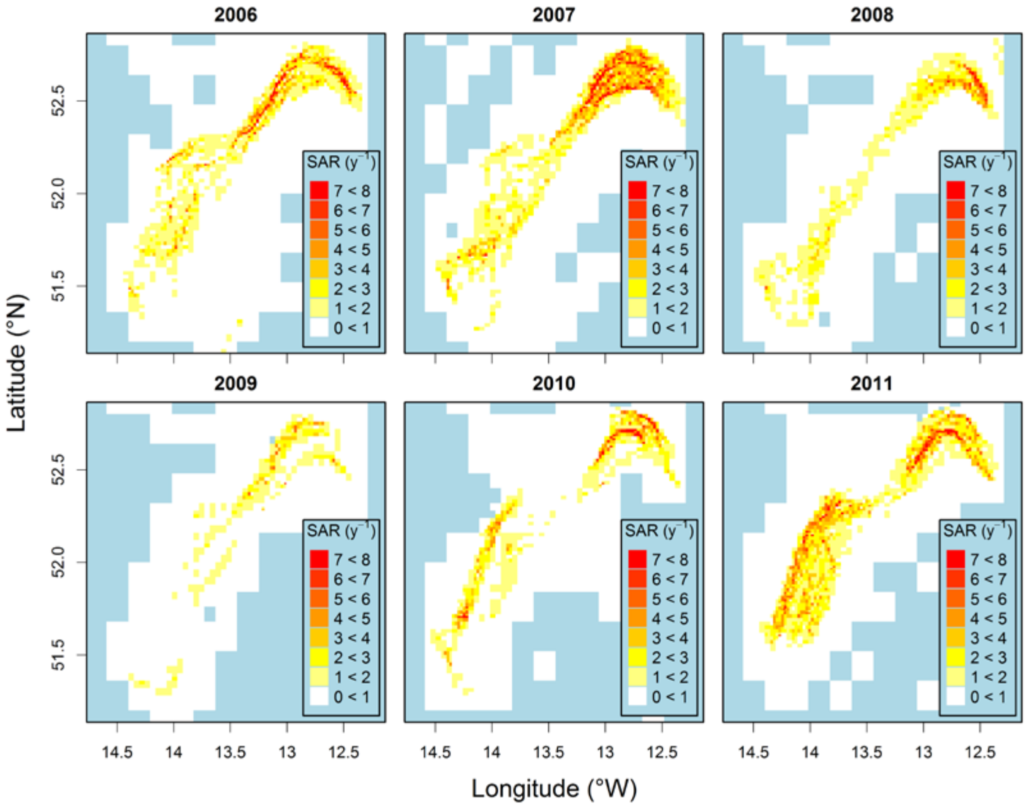

Figure 4.7.1. Swept-area ratio (SAR) or the mean number of times each grid cell is impacted by fishing gear for the years 2006–2011.

Table 4.7.1. The estimated area that is impacted by fishing gear a given number of times. The total area is estimated to be 7100km². The percentage of the total area is given in brackets.

YEAR	AREA (KM²) IMPACTED AT LEAST………			
	Once	Twice	Five times	Ten times
2006	4579 (64%)	1421 (20%)	443 (6%)	42 (1%)
2007	4977 (70%)	1852 (26%)	698 (10%)	71 (1%)
2008	4023 (57%)	1007 (14%)	251 (4%)	14 (0%)
2009	3140 (44%)	561 (8%)	109 (2%)	2 (0%)
2010	3710 (52%)	1039 (15%)	329 (5%)	33 (0%)
2011	4569 (64%)	1967 (28%)	723 (10%)	49 (1%)

Nephrops trawling has considerable impact on the benthic ecosystem but the processes involved are very complex and not that well understood or studied. However, there is an increasing realization that maintaining of key ecosystem services and preserving vulnerable species and habitats is an important aspect of sustainable management of *Nephrops* fisheries into the future. Assessing the frequency of benthic disturbance by *Nephrops* trawling is an important development in this regard. WK*NEPH* concluded that significant progress has been made towards assessing the frequency of trawl impact on the seabed however methodologies to assess and advise on the sustainability of this require further development.

4.8 Stock assessment methods

Model used: UWTV Based Approach to generate catch options

4.8.1 TV survey

The general methodology involved in UWTV surveys and the approach to providing catch advice is outlined in Section 3.

In 2012 Ireland conducted the first underwater television survey (UWTV) on the Porcupine Bank. The survey was based on a randomized fixed isometric grid design (Lordan *et al.*, 2012). The methods used during the survey were similar to those employed for UWTV surveys of *Nephrops* stocks around Ireland and elsewhere and are documented by WKNEPHTV (ICES, 2007) and SGNEPS (ICES, 2009; 2010).

In order to use the survey abundance estimate as an absolute it is necessary to correct for potential biases. For the Porcupine Bank the field of view of the camera was 0.75 m and expert judgment of the mean burrow diameter was in the range of 0.55–0.65 m. Using the simulation approach suggested by Campbell *et al.*, 2009 the estimated edge effect bias was in the range of 1.24–1.28. This seems low compared with other areas but it is based on the best judgement of burrow diameter from the footage. In future it may become possible to quantitatively estimate burrow diameter from mosaics of the footage from this and other areas. Burrow detection rates were thought to be relatively high due to good water clarity and few other burrow systems of similar size. Burrow identification could be slightly overestimated since a few fish and squat lobsters were observed at burrow entrances. The proposed cumulative correction factor for the area was 1.26 (Table below). When compared to with the correction factors applied in other areas it is quite close to the average used on other grounds.

The biases associated with the estimates of *Nephrops* abundance in the Porcupine Bank are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU16: Porcupine Bank	2012	1.26	0.95	1.05	1	1.26

The survey results as well as a per recruit analysis is described in detail (Lordan *et al.*, 2012). WK*NEPH* concluded that the approach used was appropriated but recommend that the following revision be made on the definition of reference points based on the deliberations of WK*NEPH*;

1) The biological parameters used in the population model and LCA should be updated to take account of the new maturity ogive proposed in Section 4.2.2.
2) The LCA carried out by Lordan *et al.*, 2012 was based on length–frequency distribution from 2010–2011. The stock is not expected to be in equilibrium so WGCSE should explore the impact on reference points of carrying out the analysis with new data e.g. 2012 LFDs.

WK*NEPH* recommend that WGCSE should revise as necessary the reference points based on an updated LCA and per recruit analysis provided any changes are adequately justified.

4.9 Short-term forecasts, and how the advice is derived

4.9.1 Input data

No discards have been included in the calculation of catch options due to negligible discards on observed discards trips. **WK*NEPH* recommend that discards rates be monitored and kept under review by WGCSE should this situation change.**

An estimate of mean weight in the landings is required to calculate catch options using the methodology developed by WK*NEPH* (ICES, 2009). In the case of Porcupine Bank *Nephrops* there has been significant change in mean weight linked to the decline in the stock. Prior to 2000 the mean weight was relatively stable fluctuating around 45 gr. There was a significant increase in mean weight during the period 2000–2006 due to and increasing reliance on older larger individuals in the fishery. Due to the strong recruitment observed the mean weight has subsequently declined to just over 45 gr again in 2011.

WK*NEPH* recommend that in general a three year average mean weight should be used in the calculation of catch options. In this case however the elevated mean weights observed between 2003 and 2010 should not be included in the calculation of mean weight. **WGCSE should keep the mean weight under review and move to a three year average provided mean weight in the landings return to a more stable situation.**

4.9.2 Model and software; how Y/R and SSB is derived

The general methodology to derive F reference points for *Nephrops* stocks is outlined in Section 3.

4.10 Biological reference points, reasoning behind choice of recommended exploitation level

Under the ICES MSY framework, exploitation rates which are likely to generate high long-term yield (and low probability of overfishing) have been evaluated and proposed for each *Nephrops* functional unit. Owing to the way *Nephrops* are assessed, it is not possible to estimate F_{MSY} directly and hence proxies for F_{MSY} have been determined. Three stock-specific candidates for F_{MSY} ($F_{0.1}$, $F_{35\%SPR}$, and F_{MAX}) were derived from a length-based per recruit analysis (these may be modified following further data exploration and analysis).

Density of *Nephrops* in FU 16 is considered very low (low density <0.3 m^{-2}). The stock size has increased in recent years and exploitation rates have declined. For this FU, the exploitation rate on males is usually higher than on females. Using the ICES decision framework for F_{MSY} proxies in *Nephrops* a harvest ratio consistent with a combined sex $F_{0.1}$ is accepted by WK*NEPH* as a suitable proxy for F_{MSY}.

Reestimation of these F reference points should be carried out by WGCSE 2013 using the updated maturity ogive and 2012 length distributions (see Section 4.8.1).

4.11 Recommendations on the procedure for assessment updates and further work

WK*NEPH* recommend that the fishing industry continue to provide grade landings data on an ongoing basis and allow sufficient sampling of graded landings across vessels operating in the fishery.

WK*NEPH* recommends that monitoring of maturity and presence of spermatophores be continued on this survey and that the parameter estimate be revised as necessary.

WK*NEPH* recommend that sex ratio indicators be updated and reviewed annually.

WK*NEPH* concluded that there was some evidence of sperm limitation in this stock and recommend that this should be monitored in future.

WK*NEPH* recommend that sampling of length–weight be carried out and that the length–weight parameters used for this stock be updated as necessary based on the results of this sampling.

WK*NEPH* recommends that the SpPGFS-WIBTS-Q4 index is presented and discussed annually in the assessment for this stock.

WK*NEPH* concluded that the length-based indicators remain appropriate and recommend that these should be updated in each assessment of this stock.

WK*NEPH* recommend particle tracking and exploration on environmental drivers of recruitment be continued in future given that this stock undoubtedly experience variable recruitment and is at risk of weak recruitment for periods of several years.

WK*NEPH* concluded that the UWTV survey approach used was for FU16 appropriated but recommend that the F reference points be revised by WGCSE based the new maturity ogive and updated 2012 fisheries length distributions. Changes should be adequately justified.

WK*NEPH* recommend that discards rates be monitored and kept under review by WGCSE should this situation change.

WK*NEPH* recommend that WGCSE should keep the mean weight under review and move to a three year average provided mean weight in the landings return to a more stable situation.

$F_{0.1}$ is accepted by WK*NEPH* as a suitable proxy for F_{MSY} for FU16 *Nephrops*

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5 FU 11 North Minch

5.1 Current assessment and issues with data and assessment

The sediments distribution around UK is given by the British Geological Survey. The accuracy of the currently used boundaries of what is considered *Nephrops* suitable habitat has been considered a source of uncertainty particularly in highly heterogeneous grounds such those on the west coast of Scotland where differences between fished area, surveyed area and population area are likely to exist. Recent work using VMS (Working Document Annex 4.5) has refined the overall estimate of the North Minch area. Marine Scotland Science (MSS) access to Vessel Monitoring System data (VMS) makes it possible to link geographical information on the positioning of vessels to landings data resulting in more detailed information on the spatial distribution of fishing effort in the *Nephrops* trawl fishery. A number of annual polygons based on the VMS distribution of effort (2007-2011) were generated and the union of these used to define the area of *Nephrops* ground in the North Minch. The VMS ground area used to calculate the *Nephrops* abundance in FU 11 was updated.

It is known that most of the sea lochs to the east of the North Minch FU have grounds of mud substrate that are typically fished by creel boats. In the sea lochs there is a risk of entanglement of the TV survey gears with creels fishing in the grounds; therefore the survey methodology has to be modified. A drop frame consisting of a vertically mounted camera suspended and drifted across the survey area has been used in trials recently. Both spatial extent of *Nephrops* habitat and burrow density are required to calculate an absolute abundance. Until now MSS had no indication of either value relating to the west coast Scottish sea lochs. Work has been carried out on methods to map the spatial extent of *Nephrops* habitat in the FU 11 sea lochs and an overall sea loch area estimate was proposed.

The creel fishery in the North Minch takes place mainly in the sea-loch areas, but has recently extended also to further offshore. The discard practices in this component of the fleet have not been studied and included in the assessment. The potential problems associated with the lack of creel discard data and its implications for the assessment are discussed.

5.2 Compilation of available data

5.2.1 Catch and landings data

5.2.1.1 Commercial catch data

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. Rates of discarding by length class are estimated for Scottish fleets by on-board sampling. 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 to removals. Removals are raised separately for each sex.

Reported effort by all Scottish trawlers has shown a decreasing trend since 2000 (Figure 5.2.1). The increase in lpue in 2005 is probably reflecting the increase in reported landings rather than a change in stock abundance. In general, males make the largest contribution to the landings (Figure 5.2.2). This is likely to be due to the varying seasonal pattern in the fishery and associated relative catchability (due to different burrow emergence behaviour) of male and female *Nephrops*. This occurs because males are available throughout the year and the fishery is also prosecuted in all quarters. Females on the other hand are mainly taken in summer when they emerge after egg hatching. The mean size of smaller animals (<35 mm) in the catch (and landings) is also relatively stable through time (Figure 5.2.1). Trawl and creel fisheries are sampled separately.

5.2.1.2 *Nephrops* discard survival in creel fisheries

The creel fishery in the North Minch accounts for around 20% of the total landings and exhibits typically a length composition made of larger animals (ICES, 2012). In the North Minch creel fishing occurs mainly in the inshore waters and sea lochs while the major component of the trawl fishery catch takes place in the offshore waters, although there are some overlapping between the two fleets. Discarding of undersized and unwanted animals occurs in the fishery and quarterly discard sampling has been conducted on the Scottish *Nephrops* trawler fleet since 2000, but not for the creel component of the fishery.

Studies on survival of *Nephrops* from creel fishing have been limited to using them as control groups to estimate the mortality of trawl-caught individuals. Wileman *et al*. (1999) reported that during an experiment in the Gairloch area in the North Minch, only three out of 576 controls died in captivity. Harris and Ulmestrand (2004) estimated a survival of 100% of *Nephrops* caught in baited creels off the Skagerrak, West Sweden, used as controls and maintained in holding tanks for over two weeks. Chapman (1981) estimated the survival at 97% after individuals caught in creels were transferred to cages on the seabed in the west coast of Scotland.

There is little quantitative information on the levels of *Nephrops* discards from creel fisheries on the west coast of Scotland as observer trips on board of creel boats are not being carried out as part of the MSS sampling programme. Data from creel fished areas such as loch Torridon support that the discard level in the creel fisheries is lower than the trawl fleet which is a reflection of creels higher selectivity for larger animals in the population (Adey, 2007). In addition, most studies on *Nephrops* discard survival make use of creel caught individuals as control groups for the experiments and they have shown very high survival rates. Despite this evidence, some individuals may be discarded because they are damaged while others will be lost to predators (see also WD: Annex 4.4). It is acknowledged that although a high survival rate is expected, the true value is unlikely to be 100%. However it is expected that the magnitude of the overall loss associated with the mortality of creel discarded individuals is low and given the absence of data on creel discard rates (data not collected through the sampling programme) the assumption of 100% survival is considered reasonable.

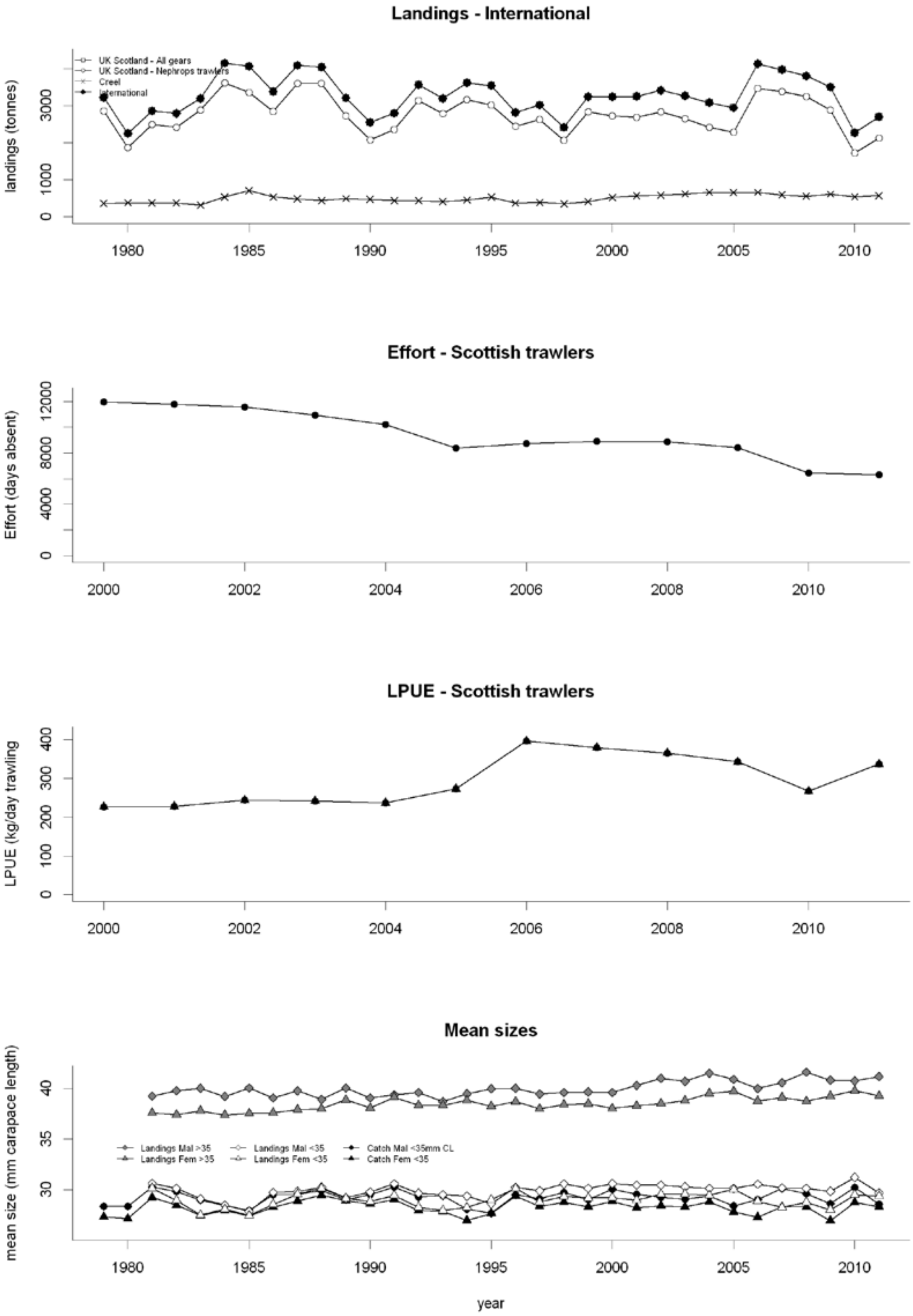
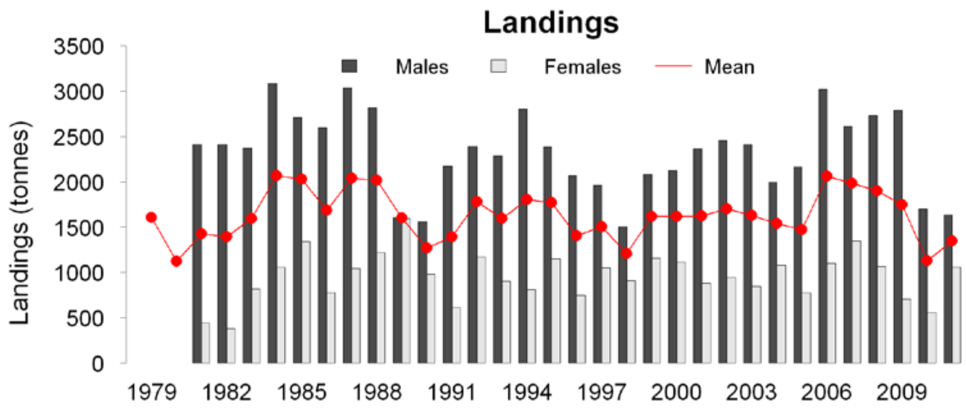


Figure 5.2.1. ***Nephrops*, North Minch (FU11). Long-term landings, effort, lpue and mean sizes. The interpretation of the lpue series is likely to be affected by the introduction of the "buyers and sellers" regulations in 2006.**



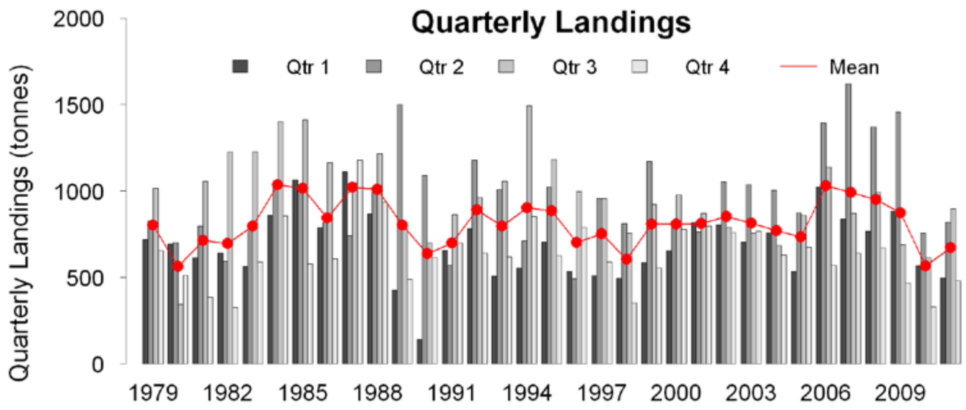


Figure 5.2.2. *Nephrops*, North Minch (FU11). Landings by quarter and sex from Scottish trawlers.

5.2.2 Biological data

Mean weights-at-age for this stock are estimated from fixed Scottish weight–length relationships (unpublished data). Relevant biological parameters are as follows: natural mortality was assumed to be 0.3 for males (Morizur, 1982) of all ages and in all years. Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females. The size at which 50% of the female animals were mature (L50) was updated for FU 11 following a recent estimate by Queirós *et al*. (2013). This estimate was based on maturity ogives produced from the calculated proportion of mature females in each size class using generalized linear models (binomial family and "logit" link function). A list of the FU 11 biological parameters respective references is given below:

Biological parameters – FU 11

Parameter	Value	Source
Discard Survival (trawl)	25%	Charuau *et al*., 1982; Sangster *et al*., 1997; Wileman *et al*., 1999
Discard Survival (creel)	100%	Wileman *et al*., 1999; Harris and Ulmestrand (2004); Chapman,1981
MALES		
Growth – K	0.16	Adapted from Bailey and Chapman (1983)
Growth - L(inf)	70 mm	Adapted from Bailey and Chapman (1983)
Natural mortality - M	0.3	Morizur, 1982
Length/weight - a	0.00028	Howard and Hall (1983)
Length/weight - b	3.24	Howard and Hall (1983)
Size at maturity	27 mm	Adapted from Bailey and Chapman (1983)
FEMALES		
Immature Growth		
Growth – K	0.16	Adapted from Bailey and Chapman (1983)
Growth - L(inf)	70 mm	Adapted from Bailey and Chapman (1983)
Natural mortality - M	0.3	As for males
Size-at-maturity	22 mm	Queirós *et al*. (2013)
Mature Growth		
Growth – K	0.06	Adapted from Bailey and Chapman (1983)
Growth - L(inf)	60 mm	Adapted from Bailey and Chapman (1983)
Natural mortality - M	0.2	
Length/weight - a	0.00074	Howard and Hall (1983)
Length/weight - b	2.91	Howard and Hall (1983)

5.2.3 Survey data

Underwater TV surveys using a stratified random approach are available for this stock since 1994 (missing surveys in 1995 and 1997). Underwater television surveys of *Nephrops* burrow numbers and distributions, reduce the problems associated with traditional trawl surveys that arise from variability of burrow emergence of *Nephrops*. TV surveys are targeted at known areas of mud, sandy mud and muddy sand in which *Nephrops* construct burrows. The survey usually occurs in May/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 methods used in the survey were similar to those employed for UWTV surveys of *Nephrops* stocks around Scotland and are documented by WKNEPHTV (ICES, 2007) and SGNEPS (ICES, 2010; ICES, 2012). In the assessment, burrow densities are raised to the total estimated area. The survey provides a total abundance estimate, and is not age or length structured. Samples are distributed randomly over the area of suitable sediment. The area calculation was based on the alpha convex-hull method to define and characterize the overall shape of a set of VMS points and is described in Section 5.3.

5.3 Stock identity, distribution and migration issues

The North Minch Functional Unit 11 (FU 11) is located at the northern end of the west coast of Scotland. Underwater TV surveys (UWTV) have been used to estimate

Nephrops norvegicus abundance in Scottish waters for a number of years. In the North Minch, UWTV surveys have been carried out since 1994 (missing surveys in 1995 and 1997). The approach consists of a sledge mounted with TV cameras and towed for a known distance over which *Nephrops* burrows are counted. Assuming a 1:1 burrow occupancy the *Nephrops* abundance in numbers is calculated and raised to the total area. Until 2010, the survey used a stratified random approach based on the sediment distribution (1775 km^2). Owing to its burrowing behaviour, the distribution of *Nephrops* is restricted to areas of mud, sandy mud and muddy sand. The North Minch FU is characterized by numerous islands of varying size and sea lochs occur along the mainland coast and exhibits the patchiest ground amongst west coast FUs. Very soft sediments are found in the southeast while coarser sandy mud prevails to the north and west. Figure 5.3.1 shows the distribution of sediment in FU 11.

The sediments distribution around UK is given by the British Geological Survey (BGS, 2002). The accuracy of the currently used boundaries of what is considered *Nephrops* suitable habitat has been considered a source of uncertainty by WK*NEPH* (ICES, 2006; ICES, 2009) particularly in highly heterogeneous grounds such those on the west coast of Scotland where differences between fished area, surveyed area and population area are likely to exist. Marine Scotland Science recent access to Vessel Monitoring System data (VMS) makes it possible to link geographical information on the positioning of vessels to landings data resulting in more detailed information on the spatial distribution of fishing effort in the *Nephrops* trawl fishery. Spatial analysis of VMS data has shown that fishing effort clearly extends outside the BGS area for FU 11, which would imply an underestimate of the stock area (Figure 5.3.1). The following section revisits the methods used to calculate the area for the FU 11 UWTV survey and explores further options based on different approaches using VMS data. See also Working Document Annex 4.5 for more detail.

5.3.1 VMS based area definition for North Minch *Nephrops* UWTV Survey

5.3.1.1 Method for VMS area calculation in the North Minch

The VMS positional data were selected from fishing vessels operating *Nephrops* gears (single rig otter trawl and multi-rig otter trawl, mesh 70–99 mm). In the North Minch the majority of vessels operating those gears land mostly *Nephrops* with small quantities of fish. To ensure that VMS points used for the area calculation match to those vessels targeting *Nephrops*, trips with at least 75% *Nephrops* by weight were selected. Geographical positions are available at least every two hours and speeds lower than 4.5 knots were assumed to be associated with fishing. The current satellite monitoring systems are restricted to all fishing vessels over 15 meters in length registered in the UK, which means that smaller trawlers and creel boats fishing for *Nephrops* are not included in this analysis. Five years of VMS data (2007–2011) were used in the analysis.

The method to define polygons around VMS datapoints is based on the alpha convex-hull (Pateiro-López and Rodríguez-Casal, 2010) which is a generalization of the convex hull concept to define and characterize the shape of a set of points. The function depends on a parameter α, which controls the level of detail of each polygon. For a sufficiently large α, the shape of a given polygon is identical with the boundary of the convex hull of the selected points. As alpha decreases, the shape shrinks until that, for a sufficiently small alpha, the shape is an empty set and the area is zero. Different values of α were tested and a value of $\alpha = 0.01$ was chosen over others by visual inspection to represent the spatial features of the polygons in relation to the corresponding VMS points. This method was previously applied to estimate the North Minch VMS area (ICES, 2010).

Different options for calculating the fishing activity area were explored:

i) Area estimated on an annual basis and averaged over a number of years;

ii) Area estimated for the entire dataset (all years);

iii) Area estimated as the intersection of annual polygons;

iv) Area estimated as the union of annual polygons.

5.3.1.2 Results

The extent of fishing activity varies from year to year and appears to be contracting between 2007 and 2011, from approximately 2500 to 2100 km^2. By inferring polygons from the entire dataset, the area estimate increases to around 3200 km^2 due to the potential inclusion of low intensity *Nephrops* fishing areas. The intersection of areas corresponding to annual polygons calculated individually for each year results in a smaller area (1800 km^2) which includes the regions of higher fishing activity common to all years. Another option is to consider the area corresponding to the union of annual polygons. This results in an area of approximately 2900 km^2 and includes the main fishing areas while it excludes some (but not all) low intensity areas (see WD Section Annex 4.5 for details and figures).

5.3.1.3 Conclusions

The VMS areas calculated for the last five years (Table 5.3.1) show some variation over time. An area corresponding to the *Nephrops* spatial extent in FU 11 must be agreed among the several options provided. The spatial extent of fishing activity is variable and a decrease has been observed since 2007. However, the extent of *Nephrops* habitat is likely to be stable from year to year and as such, taking the average VMS area over the last five years would lead to an underestimate of the area ground. Taking the alpha hull area obtained from the entire dataset would result in the inclusion of lightly fished areas where VMS pings are sparsely distributed, especially in the edges of the effort distribution and this is thought to lead to an overestimation of the area. In a situation where the spatial extent of the effort is variable and year dependent, the union of yearly estimated polygons is preferable and considered to be more realistic as this approach would include the main fishing areas while it excludes some of the low intensity areas. This results in an overall area estimate of 2908 km^2 for the North Minch (Figure 5.3.3). This area estimate is to be adopted for the workup of the last UWTV survey and from 2013, used in the FU 11 stock assessments.

The inclusion of VMS data for vessels smaller than 15 meters which will become available from 2012 onwards will provide a better picture of the effort distribution in some of the inshore locations corresponding to smaller trawl boats, but it is not expected this will have an impact in the overall area estimate for FU 11.

The North Minch is subject to both trawl and creel fishing activities, which are overlapping in most regions. However, in a number of areas there is a mismatch between the two fleets, for example in some of the sea lochs in the west of Scotland mainland. The total surface area calculated from the survey carried out at the sea lochs amounted to 105 km^2 (see Section 5.3.2) which is considered negligible compared with the main survey area. Other areas where only creel boats operate include the southeast coast of Harris and the northwest of Skye (lochs Dunvegan and Snizort). These are generally small inshore patches of *Nephrops* habitat fished by small creels boats for which VMS data are not collected. No area estimates are available for those creel regions but it would require the burrow densities to be significantly higher than the rest of the North Minch for this to have an impact on the overall assessment.

Table 5.3.1. Areas inferred from VMS data using alpha hull polygons in the North Minch (2007–2011). BGS sediment area is also shown.

Year	Areas (km²)				
	VMS area/year	BGS sediment	All years combined	Intersection Polygons	Union Polygons
2007	2513	1775	3230	1792	2908
2008	2368				
2009	2419				
2010	2239				
2011	2067				
	Average= 2321 km²				

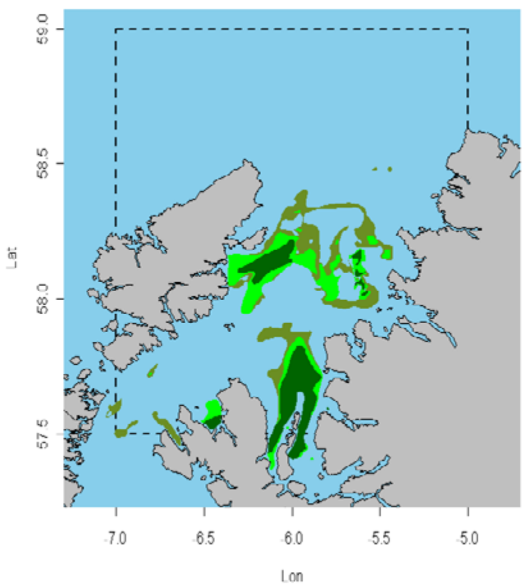


Figure 5.3.1. British Geological Survey sediment map for the North Minch functional unit. Sediments are based on the three Folk sediment classification muds: dark green – mud; green – sandy mud; olive drab – muddy sand.

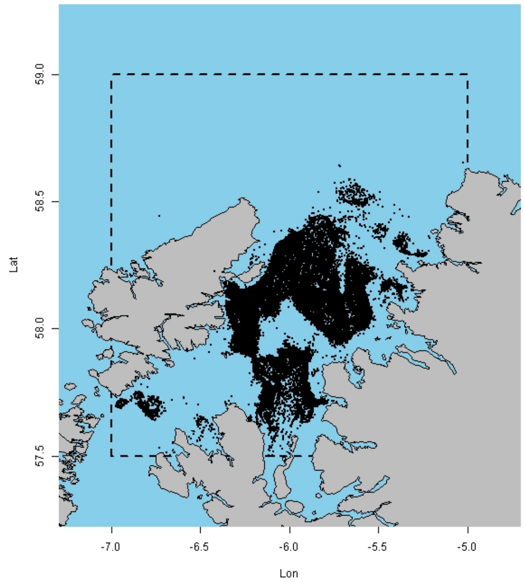


Figure 5.3.2. Distribution of VMS pings recorded from *Nephrops* trawlers (>15 m length) in 2009.

North Minch; UNION years 2007–2011.

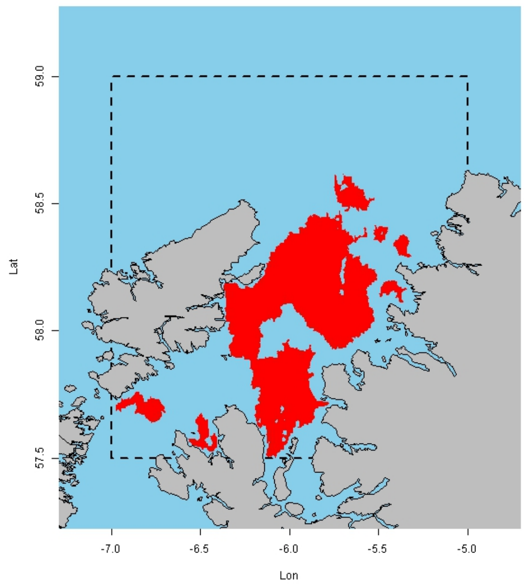


Figure 5.3.3. Union of annual polygons 2007–2011.

5.3.2 Extent of *Nephrops* habitat in the sea lochs in the North Minch

This section is a summary of the WD in Annex 4.3.

For some years the abundance estimate of *Nephrops* in the North Minch, as calculated from the annual MSS UWTV survey in the open water area of the functional unit (FU), has been seen as an underestimate of the total population in the FU. This is because the fished areas in the sea lochs in the west coast of the mainland (Figure 5.3.4) are not taken in to consideration.

To be able to provide an abundance value both *Nephrops* burrow density and the area which to raise this value to (being based on either sediment or effort distribution) are required. These data are particularly difficult to obtain from these sea lochs because:

- there is no British Geological Survey data providing sediment information;
- there is no Vessel Monitoring System (VMS) data as the majority of the vessels working these areas are <15 m;
- the areas are geographically small;
- these areas contain high densities of creels, fish farms and mussel farms.

The three surveys carried out aboard MRV Alba-na-Mara by MSS during Q1 of 2010–2012 attempted to address the first of these issues by mapping the boundary of the muddy habitat in the North Minch sea lochs. Over the three year project the vessel surveyed ten areas. Due to the strong likelihood of entanglement with creels and the associated ropes, and that the vessel was actively looking for hard ground, the standard towed TV sledge was unsuitable for this operation. As an alternative the drop frame was utilized, where the frame (containing cameras, lights, etc.) was deployed over the stern of the vessel (providing accurate positional data) and was suspended 1 m above the seabed in an attempt to avoid boulders and creel ropes.

Stations were located at the extremes of the available loch to include as much of the area as possible. Following deployment of the drop frame the vessel drifted towards or away from the shore, depending on the environmental conditions. During the deployment, various data were recorded (video footage, observations, depth, etc.) which were stored in the MSS UWTV database. Surface observations from the ship were also recorded, such as the presence of creels or rocky outcrops, and assumptions were made on fishing potential in these areas from these comments, which were also recorded in the database. On completing a TV deployment a sediment sample was taken using a Day Grab.

On completing the surveys the data were analysed with GIS software ARC MAP 10. Initially a simple point to point polygon was created between the observations closest to the shore where sediment suitable for *Nephrops* habitation was observed. These preliminary polygons were refined by using bathymetric data from SeaZone's TruDepth database. Sediment data from the particle size analysis were then introduced to the plots. These data were filtered so that only results that fell within the folk classifications of mud, sandy mud and muddy sand were plotted. Simple polygons were generated using the most outermost results within each loch. On most occasions these sediment polygons fell within the boundaries of the UWTV polygons. Where a sediment result lay outwith the UWTV polygon it was treated in one of two ways: if UWTV observations contradicted the sediment result then the sediment information was disregarded; if there was no UWTV footage to oppose the sediment data then the UWTV polygon was edited to include these points. Once the two sources of data had been merged to create 'best fit' polygons for each area, the data were transformed from latitude and longitude to British National Grid, and the surface was calculated (see Figure 5.3.5 for example in Loch Laxford).

The total surface area calculated from the survey areas available at the time amounted to 105 km^2 (Table 5.3.2) compared to 2506 km^2 in the open water area of the North Minch that is surveyed annually. This value could be increased further by investigating the areas where access was previously limited (creels, fish and shellfish farms, weather, etc.) and by considering the topography of the lochs; but this approach is not used in other assessed areas. However it is felt that any further increase in the surface area would be marginal. In addition, the high cost of further surveys should be taken into account considering the potentially low impact of any increase in the total surface area any new surveys may generate.

Burrow density has not yet been explored in the sea lochs, although comparative trials have been carried out in the Moray Firth with a modified drop frame, as described in SGNEPS 2010 (ICES, 2010). With the surface area of the sea lochs being so relatively small compared to the main survey area in the open water, it would require the burrow densities in the sea lochs to be significantly higher than the rest of the North Minch for the lochs to have any impact on the overall assessment.

Table 5.3.2. Calculated surface area (km²) of each sea loch using only sediment data and the final, merged sediment data and UWTV observations.

Location	Number of TV stations	Number of sediment samples	Surface area from PSA samples only(km^2)	Surface area all data, best fit(km2)
Loch Inchard	22	20	0.68	1.02
Loch Laxford	11	11	0.75	0.47
Loch Glen Coul	8	8	0.46	1.21
Loch Glen Dhu	6	11	0.38	0.85
Chairn Bhain	6	6	1.66	1.75
Loch Broom	20	23	3.08	6.12
Little Loch Broom	14	15	6.82	11.50
Gruinard Bay	23	25	**NA**	38.64
Loch Ewe	14	11	9.12	9.25
Loch Gairloch	19	22	3.1	8.37
Loch Torridon	31	92	36.62	26.5
Total	**174**	**244**	**62.67**	**105.67**

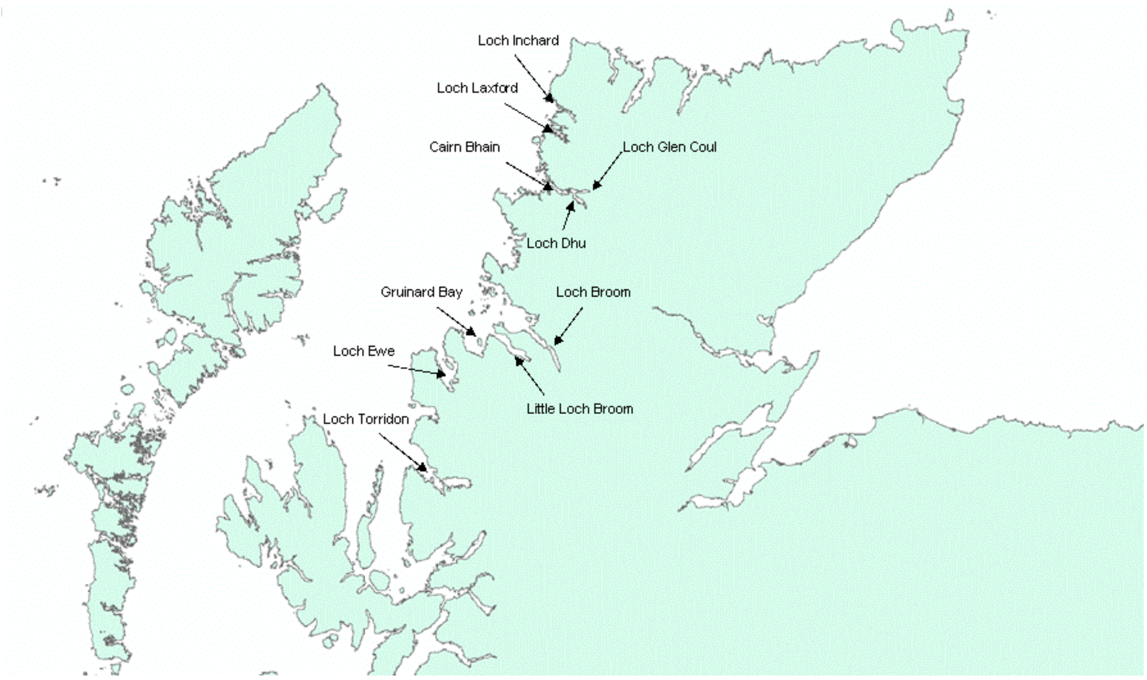


Figure 5.3.4. North Minch lochs in which UWTV surveys and sediment samples were obtained for this project.

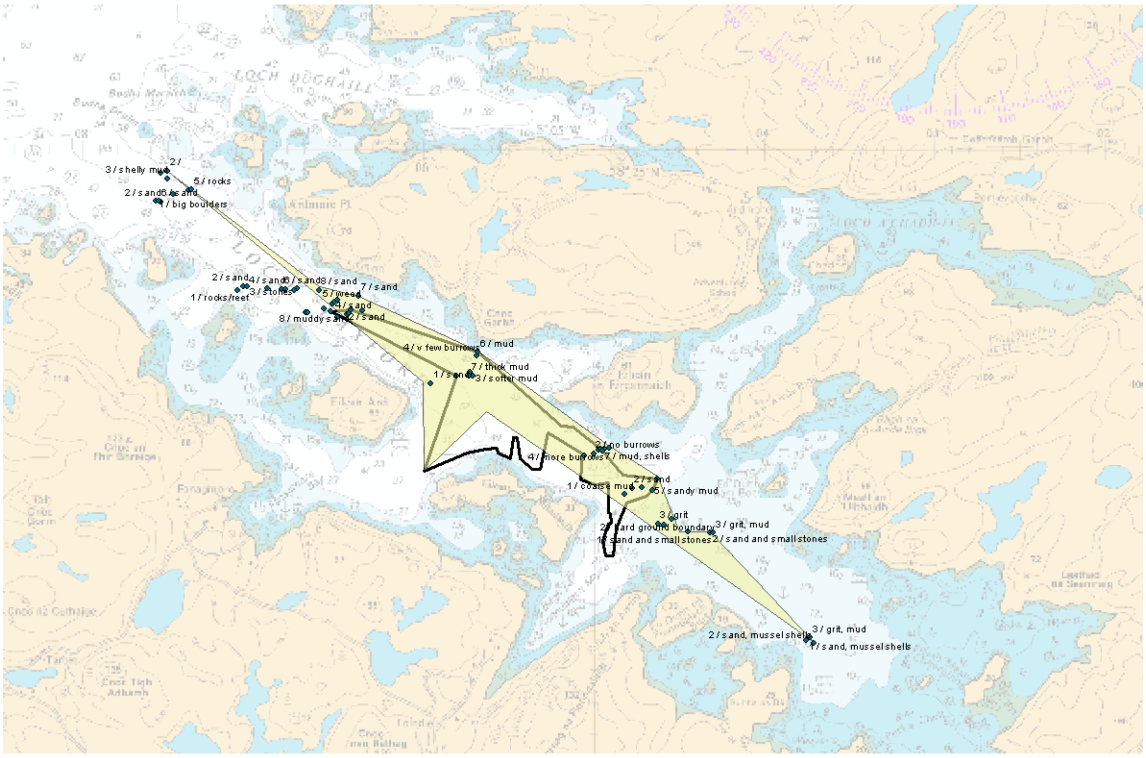


Figure 5.3.5. Loch Laxford with the final merged sediment based and UWTV data polygon (black outline).

5.4 Stock assessment methods

5.4.1 Models

Model used: UWTV Based Approach to generate catch options.

In 2009 WK*NEPH* debated the use of the surveys as either an absolute measure of abundance or a relative index (ICES, 2009). Ultimately this led to a consensus that bias corrected survey abundance estimates could be used directly in the formulation of catch advice. Two modelling approaches were used to estimate sustainable stock specific Harvest Ratio reference points; SCA (a separable LCA model by Bell) & Age Structured Simulation model (Dobby) (ICES, 2009).

The F_{MSY} proxy harvest rate values were updated at WK*NEPH*2013 (see Section 5.5) from the per-recruit analysis based on input parameters from a combined sex length cohort analysis of 2009–2011 catch-at-length data.

5.5 Biological reference points

[see WKFRAME and WKFREAME2 reports]

Under the ICES MSY framework, exploitation rates which are likely to generate high long-term yield (and low probability of overfishing) have been evaluated and proposed for each *Nephrops* functional unit. Owing to the way *Nephrops* are assessed, it is not possible to estimate F_{MSY} directly and hence proxies for F_{MSY} have been determined. Three stock-specific candidates for F_{MSY} ($F_{0.1}$, $F_{35\%SPR}$, and F_{MAX}) were derived from a length-based per recruit analysis (these may be modified following further data exploration and analysis).

There may be strong differences in relative exploitation rates between the sexes in many stocks. To account for this, values for each of the candidates have been determined individually for males, females, and the two sexes combined. The combined sex F_{MSY} proxy should be considered appropriate, provided that the resulting percentage of virgin spawner-per-recruit for males or females does not fall below 20%. If this happens a more conservative sex-specific F_{MSY} proxy should be picked instead of the combined proxy.

In the North Minch the absolute density observed on the UWTV survey is medium (~0.59 burrow/m^2). Historical harvest ratios in this FU have been above that equivalent to fishing at F_{MAX} and landings have been relatively stable in the last thirty years. $F_{35\%SpR}$ (combined between sexes) is expected to deliver high long-term yield with a low probability of recruitment overfishing and therefore is chosen as a proxy for F_{MSY}. 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. The MSY $B_{trigger}$ proposed for North Minch was based on the lowest observed UWTV abundance time-series.

The F_{MSY} proxy harvest rate values were updated at WK*NEPH*2013 from the per-recruit analysis based on input parameters from a combined sex–length cohort analysis of 2009–2011 catch-at-length data. All F_{MSY} proxy harvest rate and MSY $B_{trigger}$ values remain preliminary and may be modified following further data exploration and analysis.

Harvest ratio reference points

	Male	Female	Combined
F_{MAX}	11.1	23.0	13.2
$F_{0.1}$	6.9	12.8	7.7
$F_{35\%SpR}$	8.2	19.6	10.9

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$	538 million individuals	Bias-adjusted lowest observed UWTV survey estimate of abundance (corrected for the new VMS area estimate)
Approach	F_{MSY}	10.9% harvest rate	Equivalent to $F_{35\%SpR}$ combined sex. F_{MSY} proxy based on length based Y/R.

5.6 Recommendations on the procedure for assessment updates and further work

The North Minch is subject to both trawl and creel fishing activities, which are overlapping in most regions. However, in a number of areas there is a mismatch between the two fleets. Work on the sea loch area estimation has recently been carried out in the North Minch (Section 5.3.2). Other areas where mainly creel boats operate all year-round include the southeast coast of Harris and the northwest of Skye. These are small inshore patches of *Nephrops* suitable groundfished by small creels boats for which VMS data are not collected. Future work should consider the mismatch between the trawl and creel fleets operating in the North Minch and map the fishing areas that are currently not considered by the FU 11 UWTV survey.

5.7 References

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6 FU 6 Farn Deeps

Issues considered by the benchmark included maturity parameters, weight–length relationships, discard survival rates, change of timing of the UWTV survey and refinement of the survey design. These issues are discussed in this report, and the outcome is reflected in the stock annex. Other issues were not considered in depth.

6.1 Current assessment and issues with data and assessment

The state of the stock for FU6 is assessed using an underwater TV survey, treated as an absolute abundance estimate of individuals >=17 mm CL (carapace length) (ICES, 2009). The survey uses a fixed station design with around 110 stations covering 2750 km^2. A geostatistical method is used to estimate the overall abundance from the counts recorded by station.

Name	FU	Recent average Number of Stations (2005–2011)	Area of Ground (km^2)	Stations/ 1000 km^2	Design	CV–Relative Standard Error
Farn Deeps	FU6	108	2750	39.3	Grid	3.0%

TAC advice is derived using a Harvest Rate considered to be a proxy for fishing at MSY. The MSY proxy is calculated using a separable Length Cohort Analysis which takes the raised numbers of landings and discards by sex along with biological parameters covering growth, maturity, natural mortality and discard survival.

This established procedure was approved by the benchmark group, and is described in more detail in the stock annex.

During this benchmark we have investigated and revised the parameter estimates (where appropriate) for the maturity of both sexes and the weight–length parameters. Following changes to fishing practice, the discard survival estimate has also been changed, see Section 6.4.

The effects of these changes upon the Harvest Rates, considered suitable proxies for MSY, have been evaluated.

The parameters for growth rates and natural mortality remain unchanged as there are no new data available but it is acknowledged that these rates are critical in the determination of MSY proxies.

The timing of the UWTV survey will change in 2013 from October to June. A methodological approach to determining the most appropriate arrangements of the fixed-station design under conditions of reduced density was also discussed.

6.2 Compilation of available data

6.2.1 Biological data (Growth, maturity, natural mortality)

6.2.1.1 Maturity data–females

Nephrops maturity parameters have already been discussed in previous WK*NEPH*s, in 2004 and 2006. In these meetings standardization of methods and data collection across countries were discussed. It was agreed that the analysis of female data should be restricted to datasets that were collected within the same time-window relative to the onset of spawning. For the Farn Deeps this period should be at the latest September/October (ICES, 2006).

Maturity data for females have been recorded during the *Nephrops* catch sampling programme, by month and year (during the fishing season) since 1985 (Figure 6.2.1).

The maturity stage of females is recorded based upon a visual examination of the gonads and egg bearing condition using Symmonds maturity stages up to mid-2004 and Redant stages from the 2nd semester of 2004 onwards. The two staging protocols were harmonized to compare the entire dataset by classing Redant stage 2+ and Symmonds stage 3+ as mature (Table 6.2.1). Samples started to be stratified by length since 2001 (see section length–weight for more details).

Maturity ogives were fitted providing L50 estimates for females since 1985. Size at 50% maturity included mature females 2+ (Redant) or 3+ (Symmonds). Estimates of L50 are presented for October (Figure 6.2.2). No September data were included as the sampling is very poor for this month throughout the years.

Between 1991 and 1998 sampling was extremely poor, and L50 estimates should be analysed carefully for this period. L50 estimates have gradual increase since 2006 and stabilized around 2009.

6.2.1.2 Maturity data –males

As part of the DCF requirements *Nephrops* maturity data has been collected every two to three years (appendix masculina measurements); these data were analysed and *Nephrops* morphometric maturity was estimated.

The use of the appendix masculina to calculate size at onset of maturity (SOM) was already demonstrated and validated in other studies (Farmer, 1974; Hills, 1977, 1981; McQuaid *et al.*, 2006). Appendix masculina have been collected in the Farn Deeps for the years 2004, 2006, 2009 and 2012 (during the catch sampling programme) (Table 6.2..2) and measured by using, initially, a classic method were the appendix were measured on a glass slide using a “Wild M3” microscope with a calibrated ocular micrometre. Later, for 2009 onwards a new method was implemented by using an image software analysis (Myrmica, version 4) that allows measurements being made in a screen with more precision, where the edges of the appendix are easier to see (Figure 6.2.3).

From the three measurements types available (see Figure 6.2.3) taking the long measurement gave the best fit to the carapace length and appeared to be the best measurement type to be used. The short measurement is in some cases hard to take and also subject to more subjectivity among observers and the width showed a high dispersion of points (Figure 6.2.4).

Differences in the two methods of measurement were tested (microscope vs. Myrmica) but no differences were found (Table 6.2.5). Inter and intra variability of observer was studied as well (no significant effect was observed, by using the concordance correlation coefficient (CCC)) (Table 6.2.4).

To validate comparisons from year to year, changes to the appendixes preserved in alcohol were investigated. Effect of preservation in alcohol was tested in 40 appendices for ten months (collected in March 2012), measurements were made fresh, then after one day in alcohol, after one week and further in intervals of one month. No trend was found throughout time, so there is no evidence that alcohol affects appendices sizes Figure 6.2.5. Thus, the entire dataset can be compared without any data transformation.

Estimates of size at maturity from morphometric characteristics are based on changes in the relative growth of a body part, such as the appendix masculina in relation to body size. The point at which changes in relative growth occurs, the inflexion point can be calculated by fitting regression lines to the data. The segmented package was used in R to fit the regression model, the segmented function and also the Davies test function was used to estimate the best fit. Both give very similar results on estimating size-at-maturity (Table 6.2.5).

Results at size-at-maturity for males can be summarized as follows (see also Figure 6.2.2.6):

$L50_{2004}$= 26.73; $L50_{2006}$= 25.83; $L50_{2009}$= 29.78; $L50_{2012}$= 25.2

6.2.1.3 Length–Weight

The monthly catch sample programme has collected weights and lengths on an individual basis since 1984. Prior to 2001 there was no stratification by length, but from 2001 up to beginning 2004 the sampling started to be stratified by length (Table 6.2.6). Stratification changed in the 2nd semester 2004 where sampling has been length stratified at 20 females and 15 males per mm CL. This stratification practice is still current at the date of WKNEPS 2013.

Between 1991 and 1998 length–weight sampling was extremely temporally and spatially poor, although since 2001, length–weight sampling improved considerably.

The fitted parameters are generally quite consistent albeit with some obvious spikes. The confounded nature of the two parameters means that increases in one are compensated by decreases in the other and the predicted weights coming from these models are much less variable, at least over the most common size classes. There do appear to be within-season changes in condition factor, indicated by sequential changes in a parameter between months. For instance the intercept for males is seen to sequentially decrease through the winter season of 2008–2009 and then increase 2009–2010. This is not considered to be an artefact of fitting as each month is treated completely independently. Were the confounding of the intercept and slope to be the driving force behind differences between months it might be expected that changes would be random rather than sequential. Given that there is no regular pattern in the within-season changes to condition estimates, their use in projection is limited and so the annual values are considered more appropriate. There is no obvious trend in the predicted weights at length over the past few years and therefore the weight–length parameters proposed by the group have been calculated from the pooled samples from 2010–2012.

Separate linear models of log(weight) ~ log(length) were fitted for each month and for each sex. The same approach was taken for samples pooled to the whole year. The results of the monthly fitting process are given in Figure 6.2.7 and the annual results in Figure 6.2.8. Predicted weights-at-length resulting from the annual model are shown in Figure 6.2.9.

6.3 Stock identity, distribution and migration issues

No new data were presented regarding stock identity.

6.4 Influence of the fishery on the stock dynamic

In the previous benchmark meeting, in 2009, the discard survival was set to zero due to the practice of catch sorting and tailing whilst steaming back to port when the vessel passes over ground not suitable for *Nephrops* habitation. From 2008–2009 there was a change in this practice with substantial reduction of sorting at the quay side.

The discard survival was reviewed in 2013 on the basis that the discarding practice changed around 2008–2009, from where local vessels started to sort most of the catch while at sea, discarding at suitable *Nephrops* grounds. As well the increase of big vessels in this ground, which can spend several days at sea, also increased the discarding of *Nephrops* in suitable grounds. Additionally, due to the nature of this winter fishery, the temperature shock can be considered low and so favour the survival rate. Based on these facts the survival rate was updated to 15%.

6.5 Stock assessment methods

Was established in 2009, and is described in the stock annex. No changes were proposed.

6.6 References

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Table 6.2.1. Maturity key used in the *Nephrops* catch sampling programme. Symmonds stages were used up to 2004 and Redant stages from September 2004 onwards.

Description	Symmonds Stages	Redant stages
Empty: No signs of ovary development (white/yellow)	0,1,2	1
Maturing: First signs of maturation (light green)	3	2
Mature: Gonads full developed (dark green)	4,5	3
Resorbing: with clear signs of ovary resorbence.	VR	4
Berried		5

Table 6.2.2. Appendix masculina sampled for the years 2004, 2006, 2009 and 2012.

Year collected	Year measured	Sample number	Rejected	Method
2004	2004	627	33	Classic
2006	2006, 2012 and 2013	883	22/29	Classic/Image analysis (Myrmica)
2009	2012	672	74	Image analysis (Myrmica)
2012	2012	871	56	Image analysis (Myrmica)

Table 6.2.4. Shows the outputs of the concordance correlation coefficient (CCC) when observer measuring performance was compared within the same observer and between observers. 60 appendices were used to compare measurements within and between observers.

	c1	c2	aM1	aM2	Width
1	AML,1	AML,2	0.98612	0.990948	0.987377
2	AML,1	RJLM,1	0.981416	0.974315	0.945784
3	AML,1	RJLM,2	0.9934	0.985416	0.964453
5	AML,2	RJLM,1	0.963463	0.964293	0.943174
6	AML,2	RJLM,2	0.989523	0.978734	0.973167
9	RJLM,1	RJLM,2	0.98099	0.977217	0.955092

Table 6.2.5. Breaking points estimates using the long measurement against the CL (size at first maturity), displayed by different start values required for these functions to do the fits ("Breaking points" column). Estimates are shown for the two types of measurement method used (classic microscope and Myrmica) and also showed for both functions (Segmented function including standard error and Davis test).

	2004 - long			2006 - long						2009 - long			2012 - long		
	Microscope			Microscope			Myrmica			Myrmica			Myrmica		
Breaking Points	Segmented	SE	Davies	Segmented	SE	Davies	Segmented	SE	Davies	Segmented	SE	Davies	Segmented	SE	Davies
21.1	26.73	0.449	26.92	26.27	0.341	27.3	25.83	0.285	27.06	29.78	0.497	29.78	24.78	0.44	25.19
22.1	26.73	0.449	26.92	26.27	0.341	27.3	25.83	0.285	27.06	29.78	0.497	29.78	24.78	0.44	25.19
23.1	26.73	0.449	26.92	26.27	0.341	27.3	25.83	0.285	27.06	29.78	0.497	29.78	24.78	0.44	25.19
24.1	26.73	0.449	26.92	26.27	0.341	27.3	25.83	0.285	27.06	29.78	0.497	29.78	25.2	0.455	25.19
25.1	26.73	0.449	26.92	26.27	0.341	27.3	25.83	0.285	27.06	29.78	0.497	29.78	25.2	0.455	25.19
26.1	26.73	0.449	26.92	26.27	0.341	27.3	25.83	0.285	27.06	29.78	0.497	29.78	25.2	0.455	25.19
27.1	26.98	0.462	26.92	27.2	0.375	27.3	27.07	0.327	27.06	29.78	0.497	29.78	25.2	0.455	25.19
28.1	28.69	0.541	26.92	27.2	0.375	27.3	27.58	0.341	27.06	29.78	0.497	29.78	25.39	0.451	25.19

Table 6.2.6. Stratification by length used from 2001 up to beginning 2004. * For females there was only a requirement to get LW from five animals of 36 mm +.

Length group (CL mm)	M	F
<20	5	5
20–21.9	5	10
22–23.9	10	15
24–25.9	10	15
26–27.9	10	15
28–29.9	10	15
30–31.9	10	10
32–33.9	10	10
34–35.9	5	5
36–37.9	5	
38–39.9	5	
40–41.9	5	5*
42–43.9	5	
44+	5	

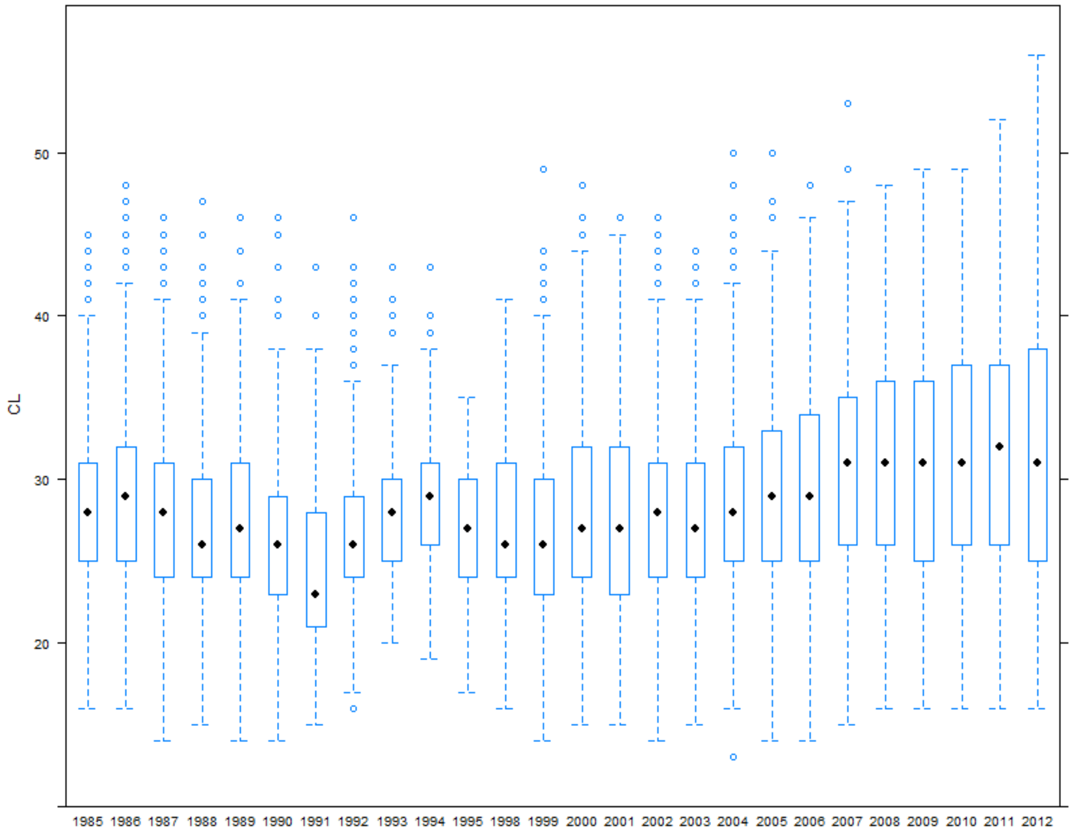


Figure 6.2.1. Female maturity sampling since 1985. Points represent mean CL (carapace length) size sampled over time. Sampling stratified by length since 2001.

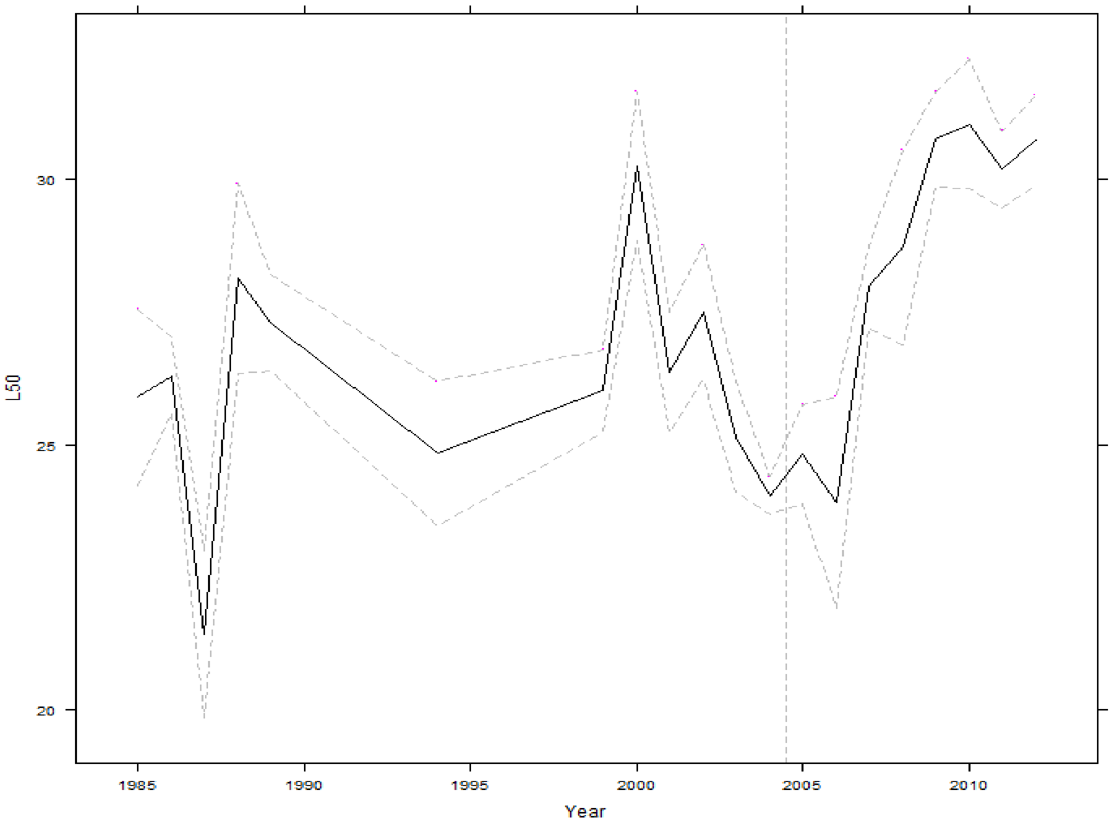


Figure 6.2.2. Evolution of L50 estimates for females since 1985 (October only). Dashed line represents the time when the new Redant maturity stage keys was implemented in the sampling programme.

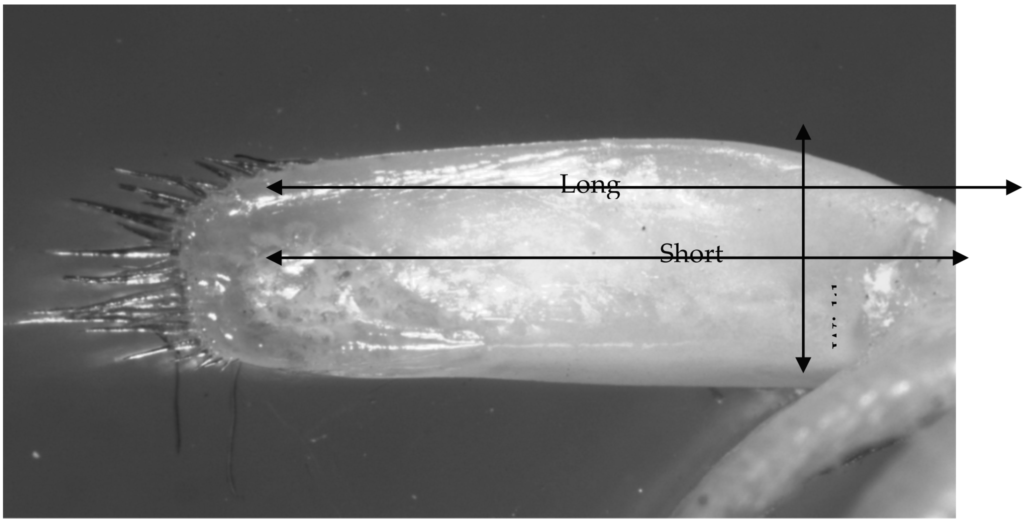


Figure 6.2.3. Image captured with Myrmica software (version 4). Measurements can be made by drawing lines (long, short and width lines are represented in the figure).

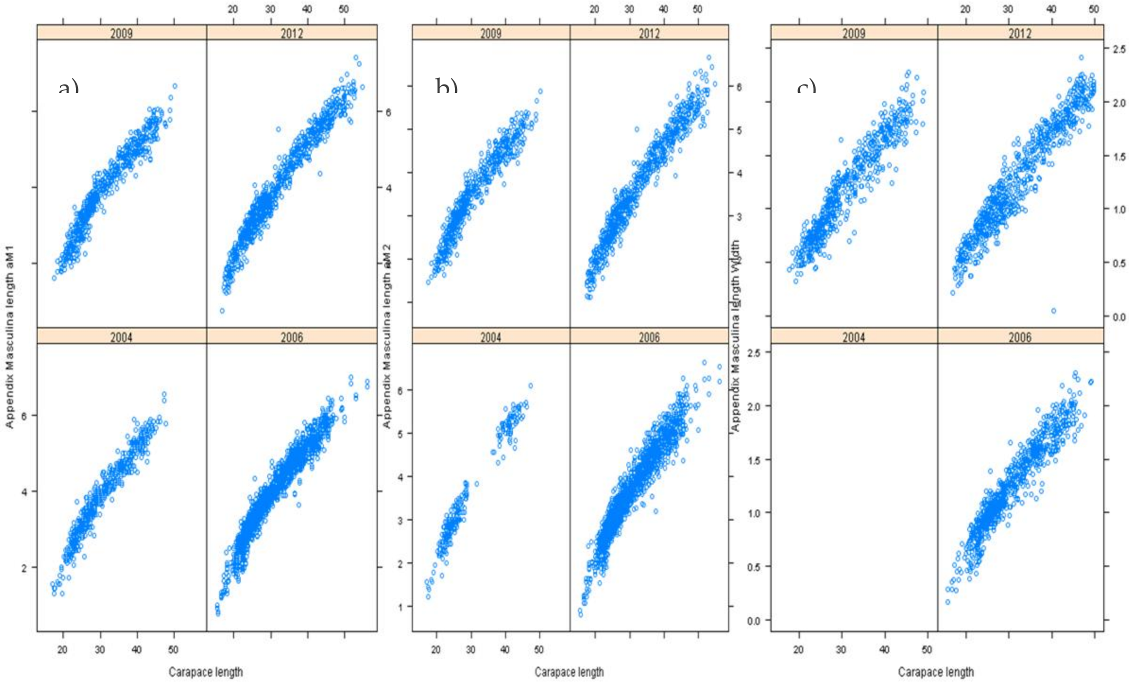


Figure 6.2.4. Regression between appendix masculina measurements and carapace length, for the three measurement types, in 2004, 2006, 2009 and 2012. a) long measurement; b) short measurement; c) width.

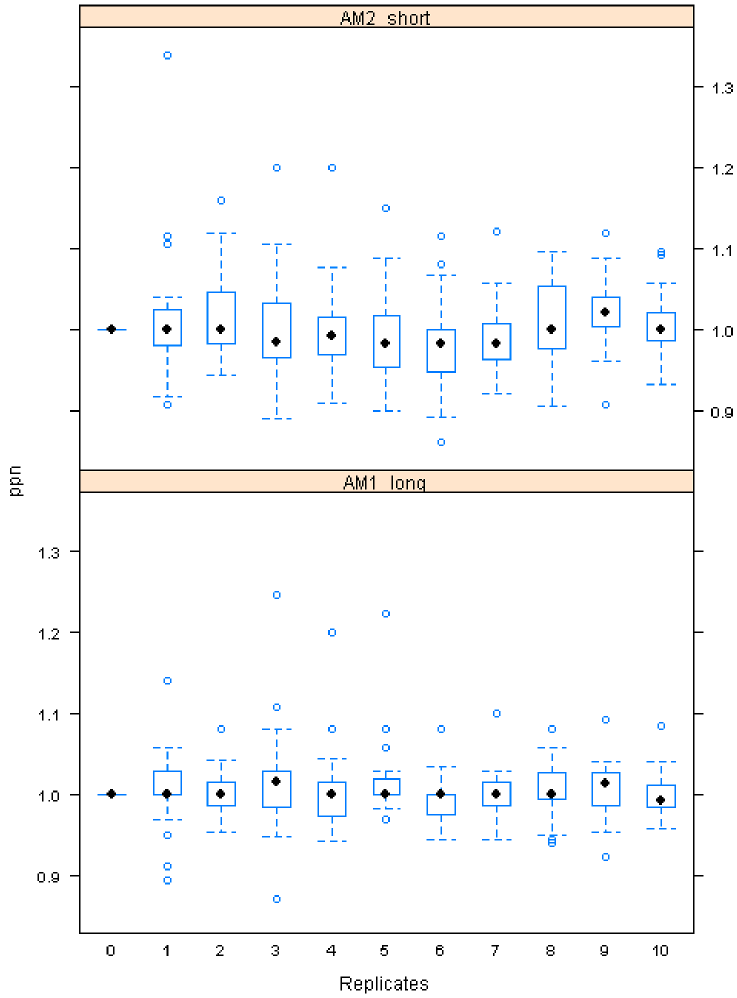


Figure 6.2.5. Appendix masculina measurements replicated thought ten months to detect any potential effect of preservation in alcohol. Where, ppn = appendix length/start length (fresh) and "Replicates" correspond to 0 = measurements made fresh, 1 = after one day in alcohol, 2 = after one week and 3 onwards = intervals of one month.

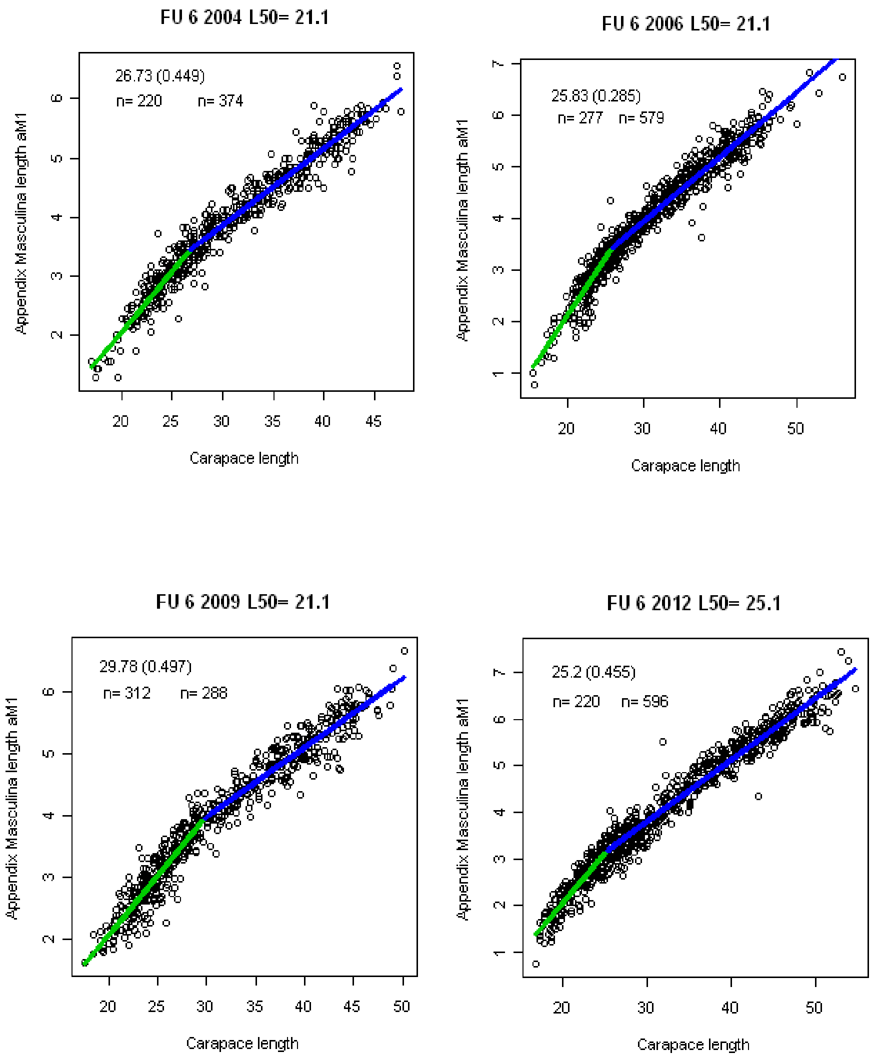


Figure 6.2.6. Breaking point estimates (long measurement with CL) by using the segmented function for the years 2004, 2006, 2009 and 2012. Breaking point estimates are shown in the top left of each figure and standard errors are shown within brackets.

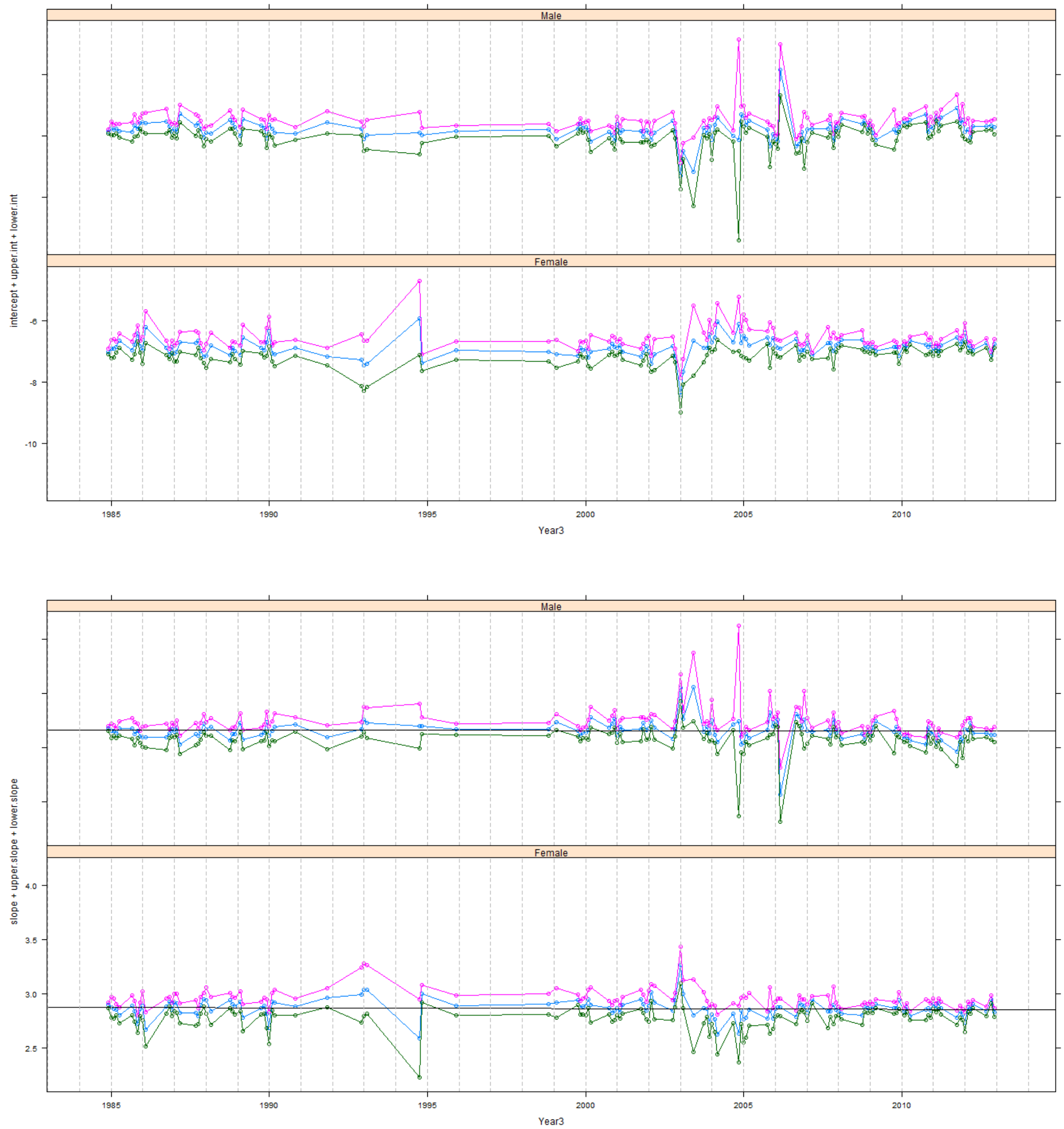
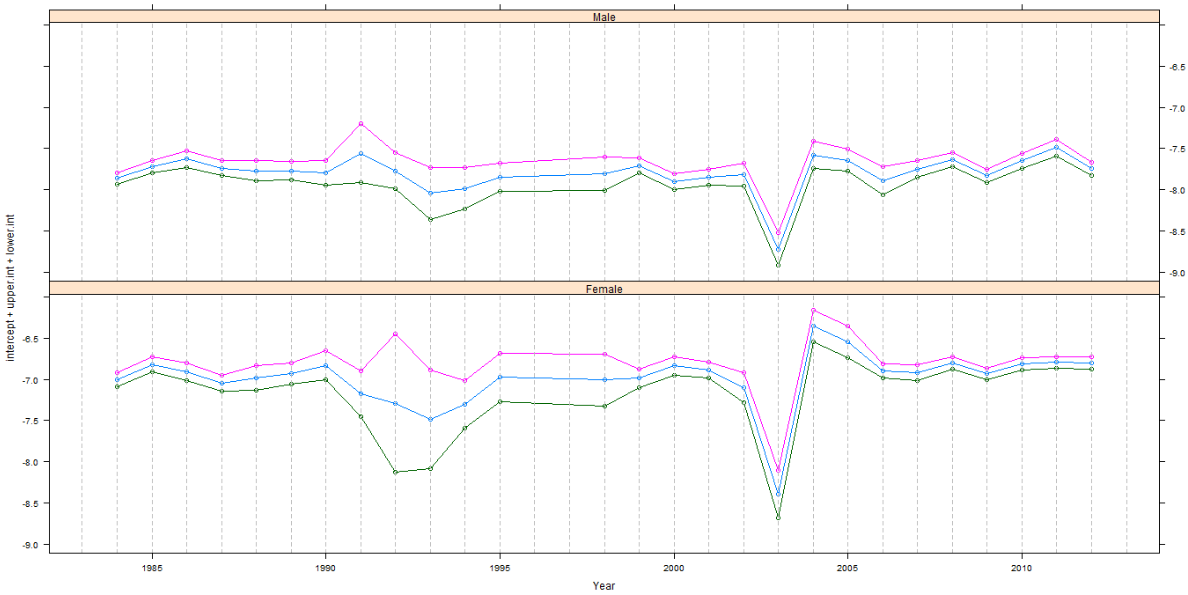


Figure 6.2.7. Evolution of length–weight parameters through time (monthly fitted), here represented by the Intercept and slope, for both sexes.



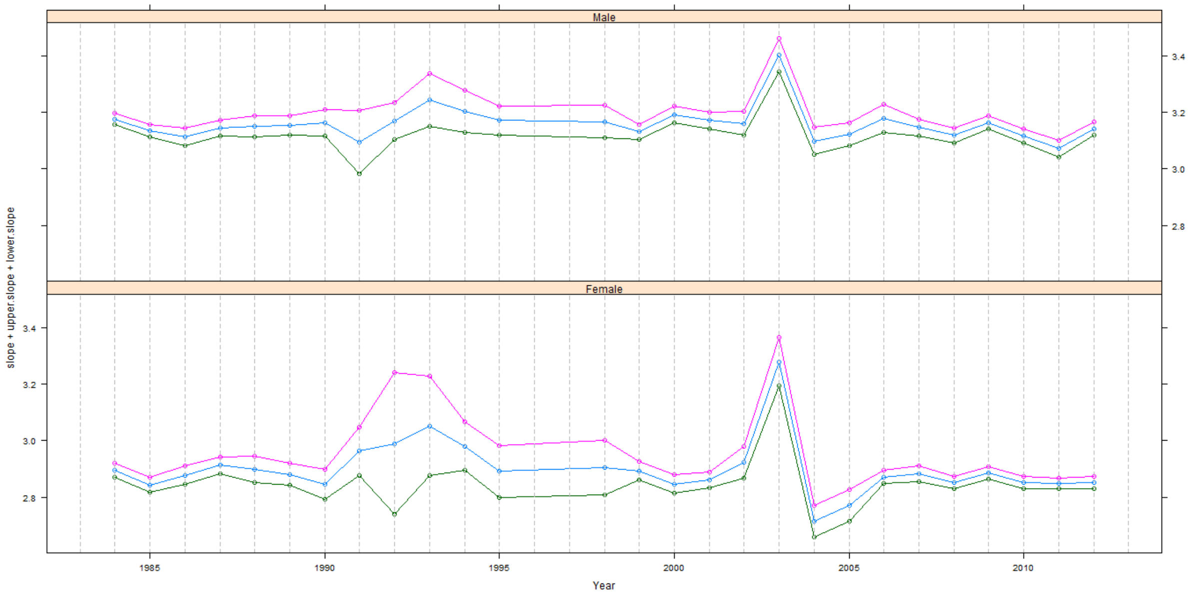


Figure 6.2.8. Evolution of length–weight parameters through time (annually fitted), here represented by the Intercept and slope, for both sexes.

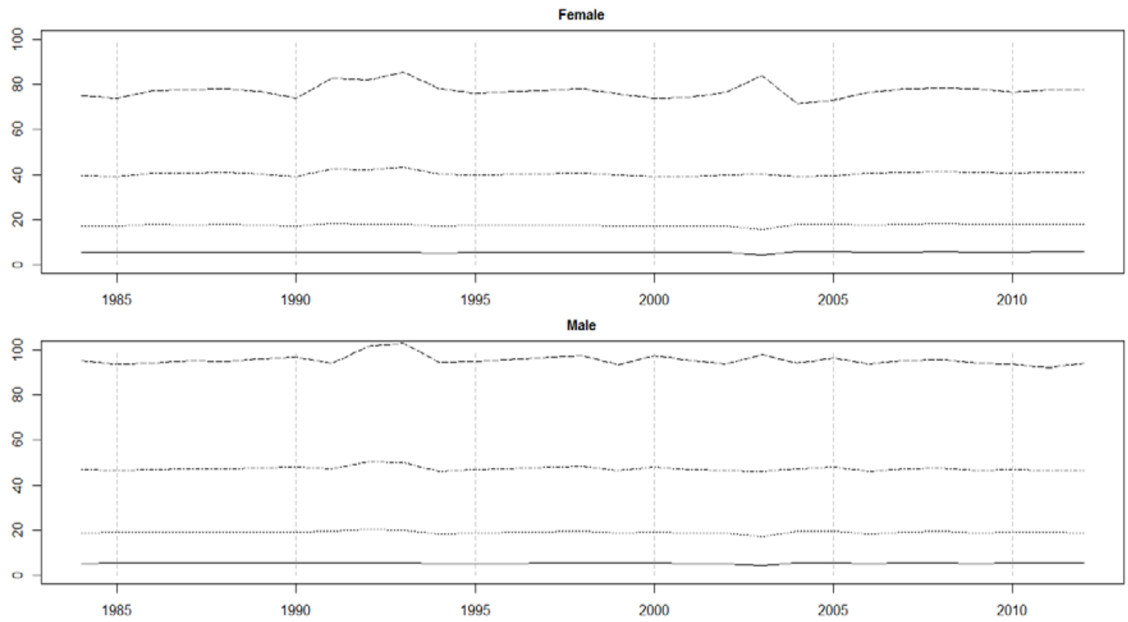


Figure 6.2.9. Predicted weights at length (for 20, 30, 40 and 50 mm CL) resulting from the annual model parameters, for both sexes.

7 FU 34 Devil's Hole

7.1 Current assessment and issues with data and assessment

The Devil's Hole is one of nine *Nephrops* functional units (FU) in the North Sea. Devil's Hole *Nephrops* were designated as a FU in 2010. Around this time it was noticed that the landings from out-with the eight FUs had been increasing and consisted of just under 10% of the total North Sea landings in 2009. A large proportion of these 'Other' landings were coming from an area of the central North Sea known as the Devil's Hole and it was agreed by SGNEPS (ICES 2010) that a new FU should be defined. FU 34 (the Devil's Hole) was defined as the six statistical rectangles: 41–43 F0–F1 (Figure 7.1.1).

Although there are regular UWTV surveys of this area, there has been limited catch sampling in recent years and the biology of the FU has not been studied.

Advice was first provided for this FU in 2012 under the *Nephrops* data-limited approach derived at the 2012 meeting of WGNSSK. This assumed the area of spatial extent of the stock to be 1100 km^2 and applied a mean weight in the landings (28 g) and discard rate from the Fladen (5%). The approach, which suggested that the long-term (ten year) average landings would result in in harvest rate below typical F_{MSY} harvest rates from other FUs, resulted in landings advice of no more than 600 tonnes. It was concluded that the stock was declining based on Scottish lpue data.

The review group for the 2012 WGNSSK highlighted that the abundance in the data-limited approach had been calculated without the application of suitable bias correction factors and in addition they recommended that the geographical distribution of *Nephrops* suitable bottom type needed to be appropriately determined as it forms the basis for estimating absolute biomass.

This benchmark reconsidered the spatial extent of the stock based on recent fishing activity and in addition considered whether sufficient commercial information were available to estimate the F_{MSY} proxy harvest rates which are required to provide advice under the standard UWTV survey method.

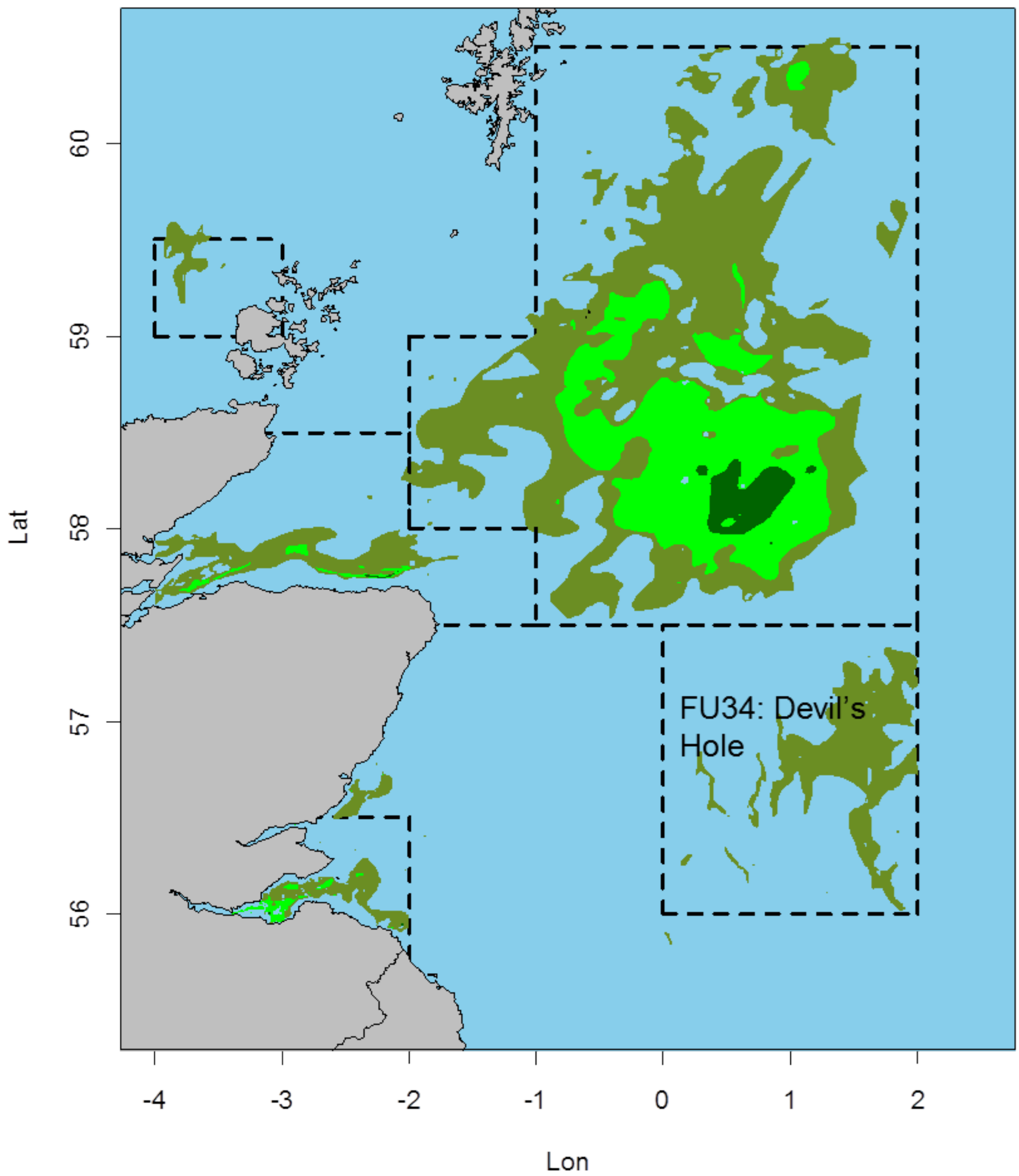


Figure 7.1.1. Areas of suitable sediment for *Nephrops* in the northern North Sea. Olive – muddy sand, lime green – sandy mud, dark green – mud.

7.2 Compilation of available data

7.2.1 Catch and landings data

Landings and effort data from logbooks are available from the Scottish fleet. Other nations supply landings data although these account for a very minor proportion of the total (Table 7.2.1). As in other *Nephrops* functional units, the reliability of the landings data is likely to have improved since the introduction of UK buyers and sellers legislation in 2006.

The following table shows the nations supplying data for this FU.

Country	Landings weight	Landings length composition	Discards length composition	Length composition in catch
Denmark	X			
Netherlands	X			
UK(E & W)	X			
UK(Scotland)	X	X	X	X

Length compositions of Scottish landings and catch (both landed and discarded components) are obtained during market sampling and on-board observer sampling respectively. Sampling levels are shown in the table below. In 2011, length–frequency samples of marketable and discarded *Nephrops* have been limited to a single observer trip and sampling was also relatively poor in 2010.

	Date Landed – Year						
Type	2006	2007	2008	2009	2010	2011	Grand Total
Observer samples*			30	3	14	12	59
Market samples	1	5	1	5	1		13

*** Observer samples (number of hauls) include both the marketable and discarded component of the catch. Some of these samples (2011 observer data) are from the small sediment trenches in 40 F0; just outside the currently defined area for FU34.**

Within MSS, when sufficient samples are available, *Nephrops* landings length frequencies are raised to trip level and then to fleet level on a quarterly basis. Since 2011, these fleets have been defined according to aggregations of métiers as agreed for the WGNSSK/WGMIXFISH data call. For *Nephrops* there are typically three main fleets or supra-métiers: i) bottom trawls with mesh size 70–99 mm, ii) bottom trawl with mesh size >= 100 mm and iii) creels. No distinction is made by gear type or vessel length within these categories. These data are uploaded to InterCatch where the international raised data are calculated.

7.2.2 Mean weights

The recent length sampling data are considered insufficient for deriving raised international landings length frequencies for use in deriving exploitation patterns (using Length cohort analysis) for use in per-recruit analysis. Instead, trends in mean sizes and weights are explored. The annual mean weight in the landings is calculated from the length–frequency data and a length–weight relationship borrowed from FU7 *Nephrops* (geographically close). Mean landed size appears to have increased in 2011 (Tables 7.2.2 and 7.2.3; Figure 7.2.1) although this may be an artefact of particularly poor sampling in this year as data are limited to a single discard trip. Therefore the average weight over the years 2007–2010 (31.76 g) is calculated for use in the *Nephrops* data-limited approach (Table 7.2.1). This should be used until there is evidence to indicate that this has changed such as when further sampled data become available.

7.2.3 Discard rates

The data from the five observer trips conducted between 2008 and 2011 (two trips in 2008) were explored on a haul by haul basis. On each of these trips *Nephrops* discards and landings are measured on a haul by haul basis. The proportion discarded by length, haul and trip are shown in Figure 7.2.2 and although discard ogives have not been fitted, the L50 appears to vary between 30 and 35 mm depending on year/ trip/haul. Discard rates (by number) are shown in Figure 7.2.3 and show some variation between trips; one trip in 2008 averages over 35% discards by number while all others are less than 20%. Annual discard rates are shown in the table below. The average value (12.9%) over 2008–2011 is used in the data-limited approach.

	DISCARD NUMBERS	MARKET NUMBERS	RATE
2008	37904.48	73804	33.9%
2009	456.6053	2199.918	17.2%
2010	304.697	76886.27	0.4%
2011	0	32195.92	0.0%
Average			12.9%

Scientific resources available for sampling landings and discards are unlikely to increase in the near future and therefore alternative approaches for obtaining the length–frequency information required to apply the full *Nephrops* UWTV approach should be considered. One option which should be followed up and which was discussed with fishing industry representatives present at the workshop was the possibility of making use of commercial grade information recorded at processing factories to augment the landings samples currently collected by MSS staff. This would require sampling of the grades and the ability to identify the grade structure to trip level, but has the potential to provide an accurate reconstruction of the landings length structure.

7.2.4 Discard survival

The workshop discussed likely discard survival rates of Devil's Hole *Nephrops*. The patchy nature of the ground at the Devil's Hole and the behaviour of the fleet (moving between suitable *Nephrops* patches) may mean that discarded *Nephrops* are not returned to the sea over suitable sediment. In such circumstances, it is assumed that there is no discard survival. This is in line with previous assumptions for the Farn Deeps.

7.2.5 Biological data

No specific biological studies have been conducted for this functional unit. The calculations of mean weight have made use of the length–weight parameters of Fladen *Nephrops* (FU7). In future, it is likely that the assessment will require other biological parameters (as in the full UWTV survey approach). The workshop considered that it would be most appropriate to use those from the Fladen; an offshore geographical neighbouring FU.

Parameter	Value	Source
MALES		
Length/weight - a	0.0003	Howard and Hall (1983)
Length/weight - b	3.25	Howard and Hall (1983)
FEMALES		
Length/weight - a	0.00074	Howard and Hall (1983)
Length/weight - b	2.91	Howard and Hall (1983)

7.2.6 Survey data

The Devil's Hole is covered by an underwater television (UWTV) survey conducted by MSS. The survey uses the same towed sledge and operating procedures as other FUs in the northern North Sea. Prior to 2009, UWTV surveys were conducted at the Devil's Hole on an opportunistic basis and station locations on these early surveys were randomly selected from within the area of suitable sediment (according to the BGS sediment map). Since 2009, the survey has used a fixed station design, with station locations chosen from the set of 2008 VMS pings (Figure 7.2.4). General survey protocols and analysis methods for underwater TV survey data are similar for each of the Scottish surveys and follow guidelines established by SGNEPS (ICES, 2008 and 2009).

On average, about 15–20 stations have been considered valid each year in the recent period which equates to approximately nine stations per 1000 km^2 given the estimates of area in Section 7.3 (which is towards the lower end of station densities across surveyed FUs).

Although station density is higher in FU34 than FUs 7 and 12, the relative standard error of the density estimate is typically higher due to the greater variability of observed densities across the ground. In the recent period, the relative standard error for the Devil's Hole density estimate has fluctuated around the level recommended as adequate by SGNEPS and averaged over 2009–2011 is 0.22 (recommended <0.2). (Table 7.2.4).

In order to improve the precision of UWTV survey density estimates from this area, it is recommended that the survey should aim to increase the number of stations conducted with sufficient geographical spread to cover the individual mud patches. In 2010, 20 stations were surveyed which resulted in a CV of 17%, so potentially this could be used as a target for future surveys.

UWTV relative to absolute conversion factors

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as absolute (required for both the *Nephrops* data-limited approach and the full UWTV survey approach), it is necessary to correct for these potential biases. The conversion factors are based on simulation studies, preliminary experimentation and expert opinion.

For the Devil's Hole, the footage, in terms of burrow complex diameter appears very similar to those apparent at the Fladen. The edge effect was therefore estimated as 1.45 (from Campbell *et al*., 2009b). Burrow detection rates were believed to be relatively high due to the excellent water clarity and burrow identification was believed to be 100% due to a lack of other burrowing fauna. The cumulative correction factor for the Devil's Hole was calculated as 1.4. This is higher than the correction factor in other FUs.

	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU34	1.45	0.95	1	1	1.4

7.2.7 Commercial data (lpue)

Landings and effort (in days) are available for Scottish vessels from logbook data. These are available from 2000 onwards and are shown in Table 7.2.5 and Figure 7.2.5. Although such data are often used as supporting indicators of stock trends, the effort and lpue are not standardized and therefore do not account for changes in efficiency, spatial and seasonal distribution or other factors that could influence the trend in lpue over time. They should therefore be used as indicators of abundance with caution.

Given that the fleet fishing at the Devil's Hole consists of large vessels (carrying VMS), it may be possible to integrate VMS effort and logbook data to obtain an index which is a more reliable indicator of abundance. Such an approach could be explored further in future.

Table 7.2.1. Total landings by country for Devil's Hole *Nephrops*, FU 34.

YEAR	UK SCOTLAND				UK (E,W &NI)	DENMARK	NETHERLANDS	TOTAL
	Nephrops trawl	Other trawl	Creel	Sub-total				
1991	83							
1992	106							
1993	44							
1994	129							
1995	132							
1996	128							
1997	99							
1998	88							
1999	202							
2000	185							
2001	270							
2002	343							
2003	674							
2004	489							
2005	379							
2006	448							
2007	715							
2008	937							
2009	1297	8	0	1305	0	0	0	1305
2010	712	18	0	730	25	1	1	757
2011	423	0	0	423	10			433

*** provisional.**

Table 7.2.2. *Nephrops*, Devil's Hole (FU34): Mean weight (g) in the landings, 2006–2011.

YEAR	MALE	FEMALE	OVERALL
2006	27.03	17.53	22.93
2007	31.19	16.94	26.27
2008	36.83	21.82	30.08
2009	46.83	24.01	39.62
2010	38.22	18.94	31.07
2011	63.25	25.47	42.05
Average (07–10)			31.76

Table 7.2.3. *Nephrops*, Devil's Hole (FU 34): Mean sizes (CL mm) above and below 35 mm of male and female *Nephrops* in Scottish landings, 2006–2011.

Year	Landings			
	< 35 mm CL		> 35 mm CL	
	Males	Females	Males	Females
2006	29.7	29.8	39.7	38.1
2007	30.4	28.7	40.5	39.2
2008	31	30.5	40.3	39.6
2009	31.7	31.1	41.3	40.6
2010	32.2	29.9	39.6	39.4
2011	31.7	30.7	43.7	40.4

Table 7.2.4. *Nephrops*, Devil's Hole (FU34): Results of the 2009–2011 surveys.

Year	Stations	Mean density (uncorrected)	95% confidence interval	Absolute density estimate	95% confidence interval (absolute)	Relative standard error (CV)
		burrows/m^2	burrows/m^2	burrows/m^2	burrows/m^2	burrows/m^2
2009	14	0.36	0.17	0.26	0.12	0.24
2010	20	0.32	0.11	0.23	0.08	0.17
2011	15	0.26	0.13	0.19	0.09	0.25

Table 7.2.5. *Nephrops*, Devils Hole (FU 34): landings, effort (days fishing) and lpue (kg/day) for UK bottom trawlers landing in Scotland and fishing *Nephrops* with codend mesh sizes of 70 mm or above, 2000–2011.

Year	Landings	Effort	LPUE
2000	185	3391	54
2001	270	3142	86
2002	343	2022	169
2003	674	2614	258
2004	489	1551	315
2005	379	1545	245
2006	448	1440	311
2007	715	1824	392
2008	937	1673	560
2009	1306	1921	680
2010	730	1465	498
2011	423	1041	406

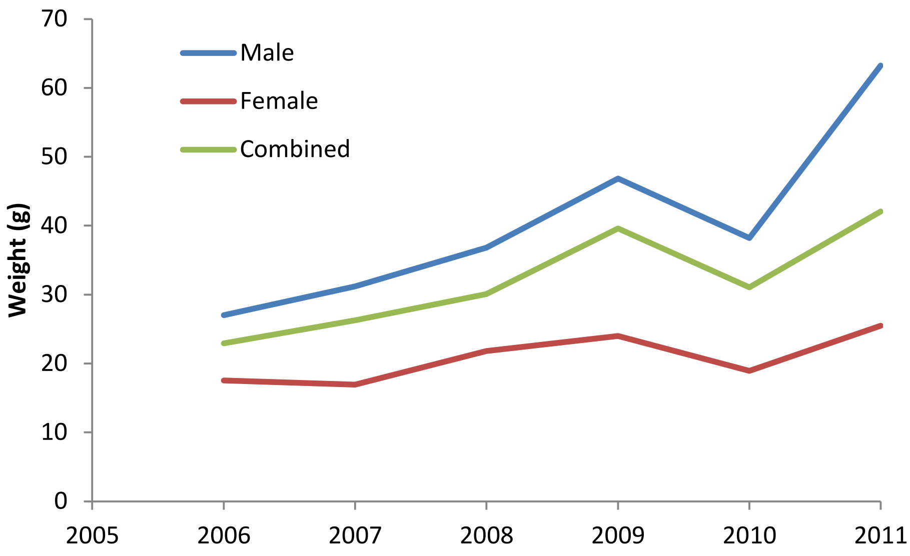


Figure 7.2.1. Mean weight in landings derived from market and observer sampling.

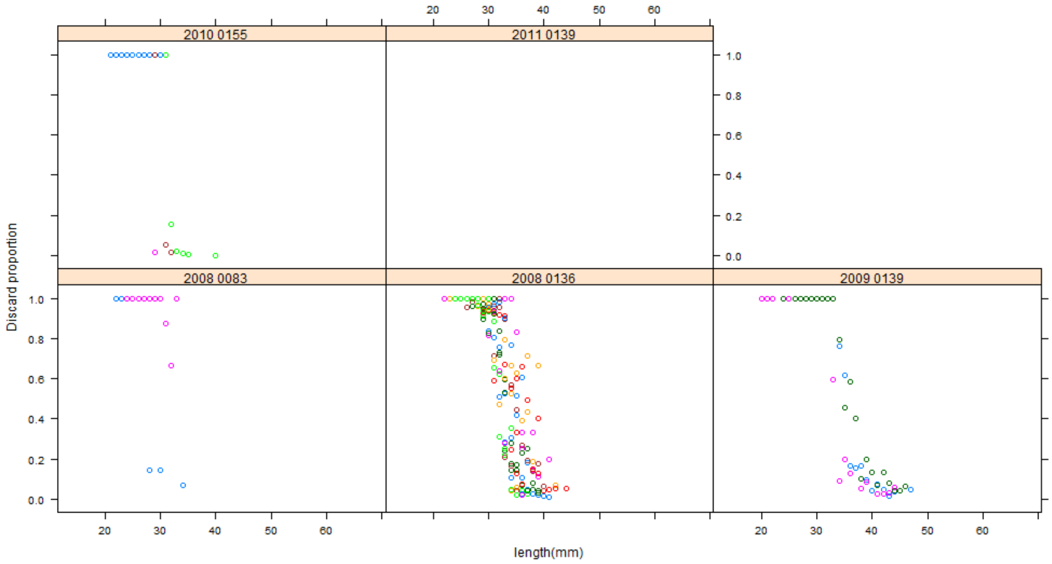


Figure 7.2.2. Discard ogives by trip. Points from different hauls within a trip are denoted by different colours.

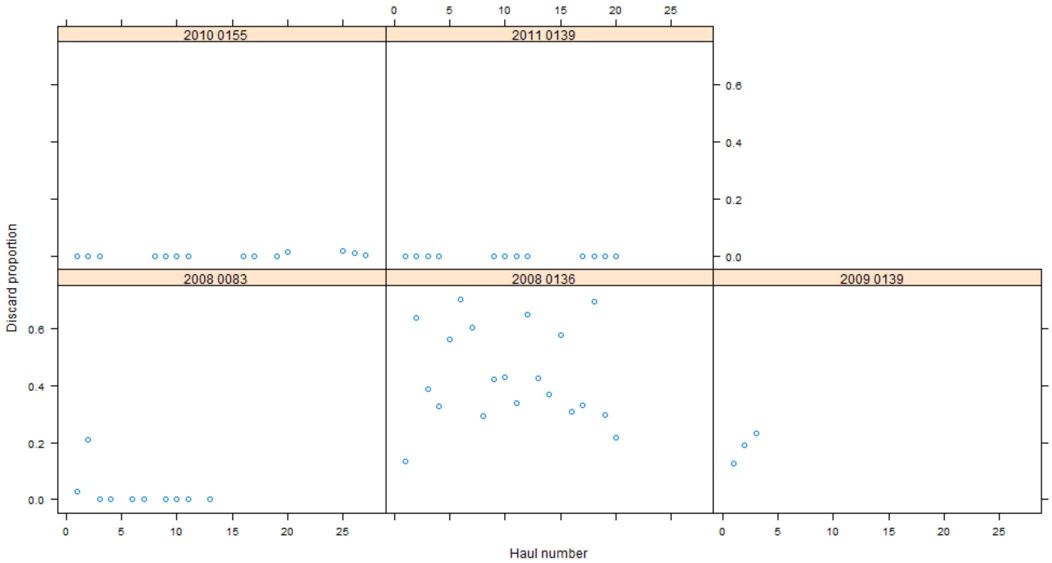


Figure 7.2.3. Discard rate (in number) by haul and trip.

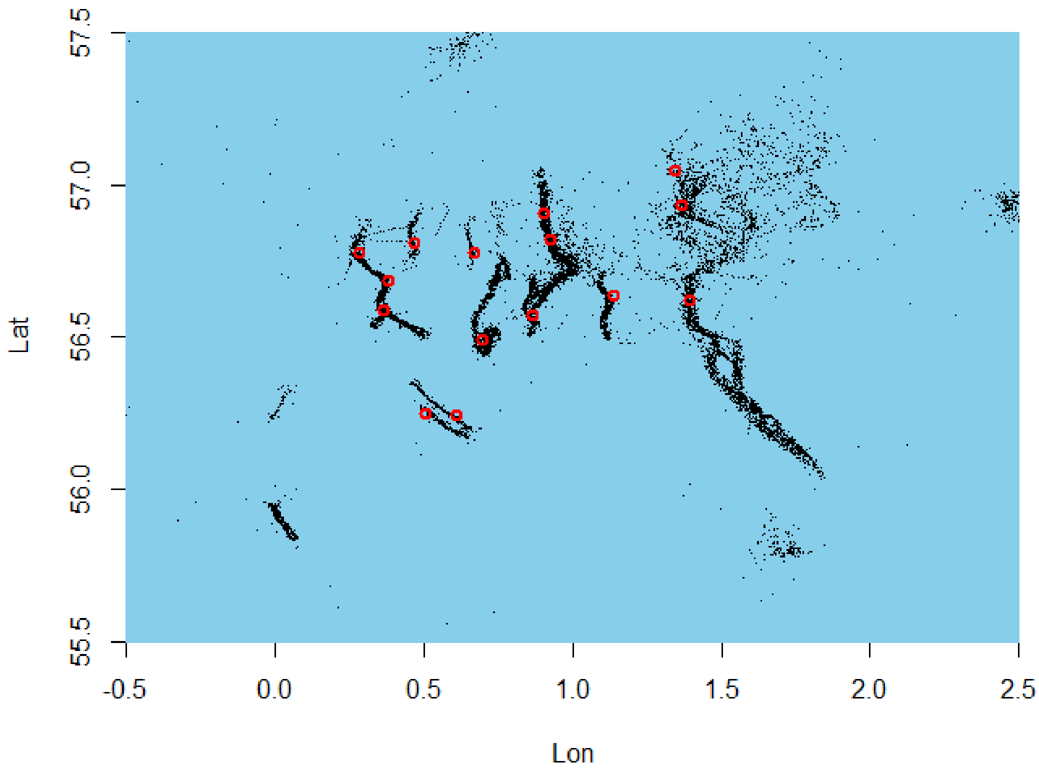
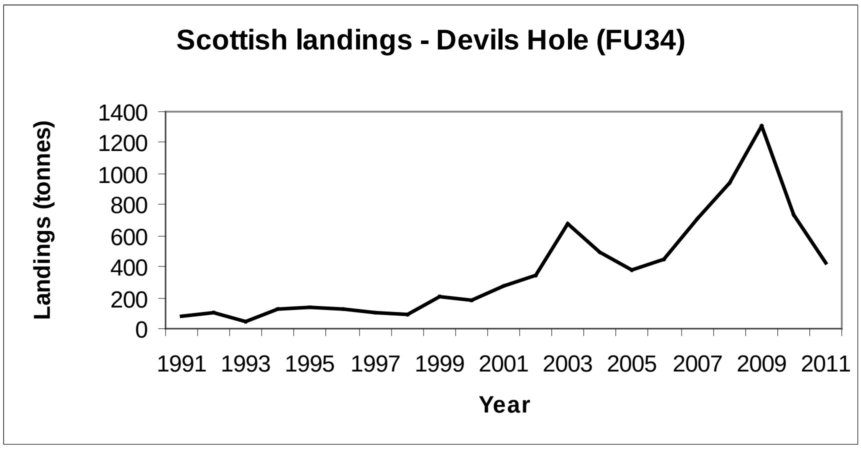
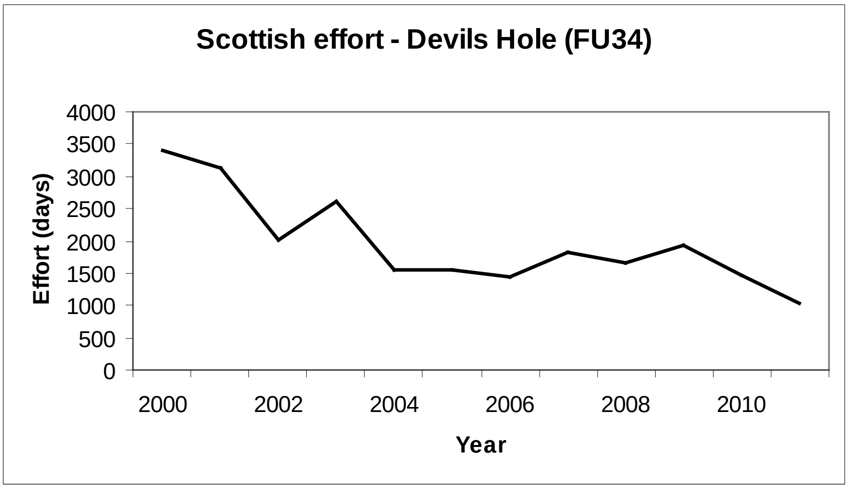


Figure 7.2.4. UWTV survey station locations (red circles) compared with 2008 VMS data (black points).





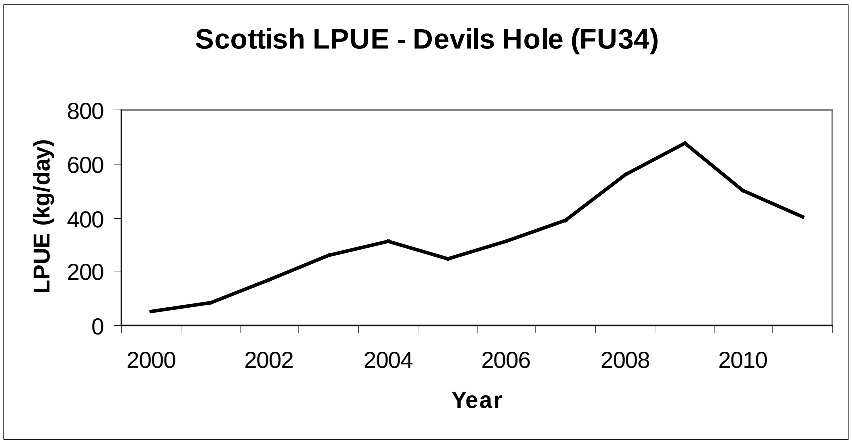


Figure 7.2.5. *Nephrops*, Devil's Hole (FU 34). Scottish landings from 1991 to 2011, effort (days) and lpue (kg/day) by Scottish trawlers.

7.3 Stock identity, distribution and migration issues

Nephrops are dependent on particular types of seabed sediment with a preference for fine muddy sediments (silt & clay content of 10–100%) suitable for excavating burrows (Farmer, 1975; Afonso-Dias, 1998). Therefore, there is a close relationship between the distribution of *Nephrops* stocks and sediment type. A British Geological

Survey (BGS) map of the North Sea (Figure 7.1.1) shows a number of patches of muddy sand (10–50% silt and clay) in the central North Sea, to the south of the Fladen (total area 4000 km^2). This area is known as the Devil's Hole and consists of a number of narrow trenches (up to 2 km wide) running in a north–south direction with an average length of 20–30 km. These trenches fall across seven ICES rectangles: 41–43F0, 41–43F1 and 40F0.

Work presented in Campbell *et al.* (2009a) has shown BGS maps to be inaccurate in some areas. At the Devil's Hole, analysis has shown differences between BGS sediment types and actual sediment composition obtained by particle size analysis of sediment samples from MSS surveys (Figure 7.3.1). This could potentially be due to the relatively coarse sampling resolution of the original BGS samples (on which their maps have been based) compared to the apparently very narrow patches of sediment. In other areas this has resulted in the spatial extent of *Nephrops* being defined using maps of fishing activity (vessel monitoring system data) instead of sediment data. A comparison of the sediment map and VMS data associated with a landing of *Nephrops* shows that the spatial extent of the fished area is somewhat less than that apparent from the BGS map (Figure 7.3.2).

7.3.1 Calculation of spatial extent of stock from VMS data

The spatial extent of *Nephrops* as derived from VMS data was explored using the alpha convex hull method (Pateiro-López and Rodríguez-Casal, 2010) to identify a polygon encompassing the VMS pings associated with *Nephrops* fishing. The alpha convex hull method makes use of a parameter α to control the level of detail of the polygon, ranging from 'crude' for sufficiently high values of α to 'fine' for small values of α (resulting in an empty set when equal to zero). The method allows for multiple polygons and holes in the polygons. The method is implemented in R using the alphahull library (Pateiro-López and Rodríguez-Casal, 2009). Mesquita *et al*. (2010) previously explored the sensitivity of estimated shapes and areas to alternative values for the alpha parameter for North Minch *Nephrops* VMS data and concluded that a value of alpha=0.01 enclosed the major areas of fishing activity, but excluded those with a low intensity of VMS pings. In addition in FU34, polygons with <20 VMS pings were excluded from the total area to avoid the creation of many small patches.

Initially, *Nephrops* fishing was identified as VMS pings with speeds 0.5–4.5 knots, mesh sizes 70–99 mm from trips recording a *Nephrops* landing (obtained by linking VMS to logbooks). On the advice of the fishing industry a maximum speed of 3.8 knots was used to filter the data.

A further difficulty associated with defining the spatial extent of the stock using VMS data in this area is that the fishery is mixed. A significant proportion of the landings from these trips consists of species other than *Nephrops* (Figure 7.3.3) so therefore not all VMS pings are necessarily associated with *Nephrops* ground and the ground is known to be relatively patchy. A number of approaches were taken in an attempt to discover whether particular parts of the fished area are more associated with *Nephrops* or whitefish catches including consideration of MSS observer data and actual sediment samples collected on UWTV surveys. The location of these observations compared to the estimated VMS polygon is shown in Figure 7.3.4. Virtually all samples/observations included *Nephrops* (or *Nephrops* burrows) and there was no evidence to suggest particular discrete VMS areas as non-*Nephrops* grounds although it should be noted that these data are relatively limited (Figure 7.3.4).

Despite this, a further filter was applied to the VMS data to exclude trips with <30% *Nephrops* in their landings (i.e. those not targeting *Nephrops*) which results in a ~10% reduction in the area estimate.

The fished area varies quite significantly between years as shown in Figure 7.3.5 and the text table below. However, given that the spatial extent of suitable habitat for *Nephrops* is likely to remain stable from year to year, the workshop agreed that the entire dataset (all years) should be considered in the calculation of the area of spatial extent. A number of different approaches were investigated which made use of all the VMS data:

- area of polygons estimated from alpha convex hull analysis of combined (2007–2011) data;
- average of annual area estimates;
- area of intersecting annual polygons;
- area of union of annual polygons.

The alpha convex hull analysis of the combined dataset resulted in a much increased area estimate (and potentially overestimated) of over 2500 km^2 and included much of the area in the northeast where the VMS points are too sparsely distributed to be included in the convex hull analysis conducted on an annual basis. The increased density of points resulting from the amalgamation of years of data means that this area (northeast) is no longer excluded due to low intensity of points by the alpha convex hull method with α=0.01. The area of the intersecting annual polygons is relatively low resulting from the large number of relatively small mud patches which are not consistently fished from year to year. An alternative approach (agreed by WK*NEPH*) making use of the full set of VMS data is to use the union of the estimated annual polygons. The resulting set of polygons is shown in Figure 7.3.6.

YEAR		AREA (KM^2)
	2007	1060
	2008	1130
	2009	1283
	2010	980
	2011	664
Average		1023
union		1753
intersect		457

While considering the fished area, a number of additional areas of fishing activity were identified to the south of the previously defined area; in statistical rectangles 39F0 and 40F0. These contribute only a small amount in terms of total area (~100 km^2) and landings and are therefore currently not included in the spatial extent of the stock.

The spatial extent across rectangles 41–43F0–F1 is estimated as 1753 km^2.

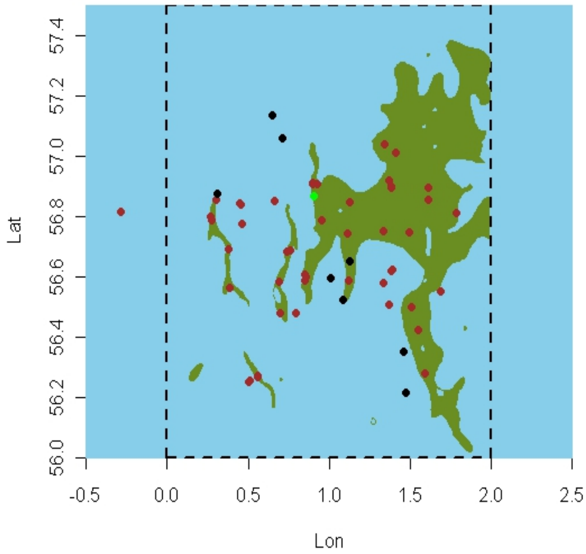


Figure 7.3.1. Distribution of sediment types (according to 'Folk' classification) from particle size analysis of sediment collected at UWTV survey stations: black = sand; brown/red = muddy sand and green = sandy mud. The olive area is BGS muddy sand.

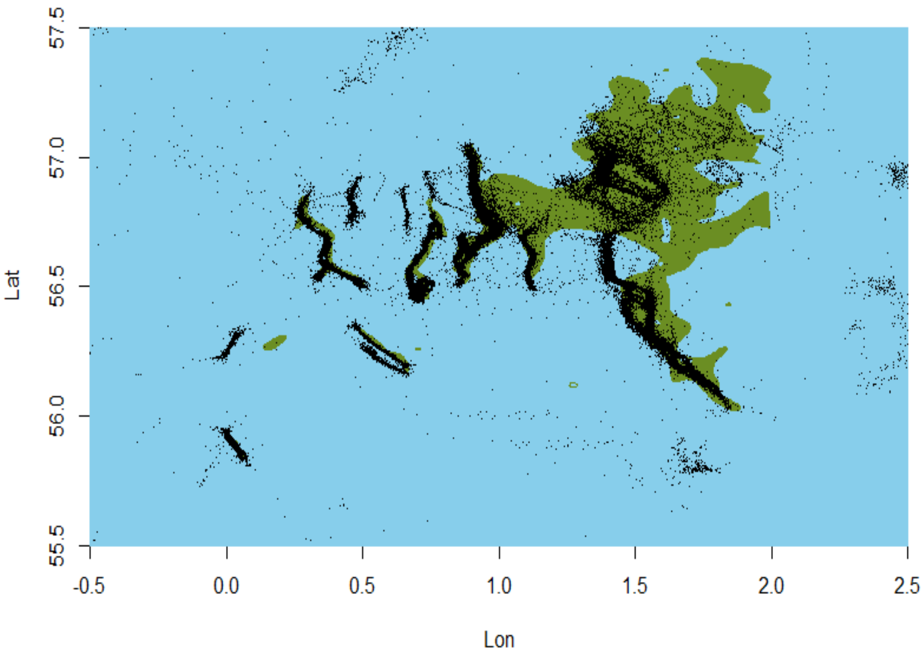


Figure 7.3.2. Comparison of BGS sediment map with VMS data from Scottish trawlers (2007–2011) filtered for *Nephrops* landings >30% of total, speeds of 0.5–3.8 knots and mesh size 70–99 mm.

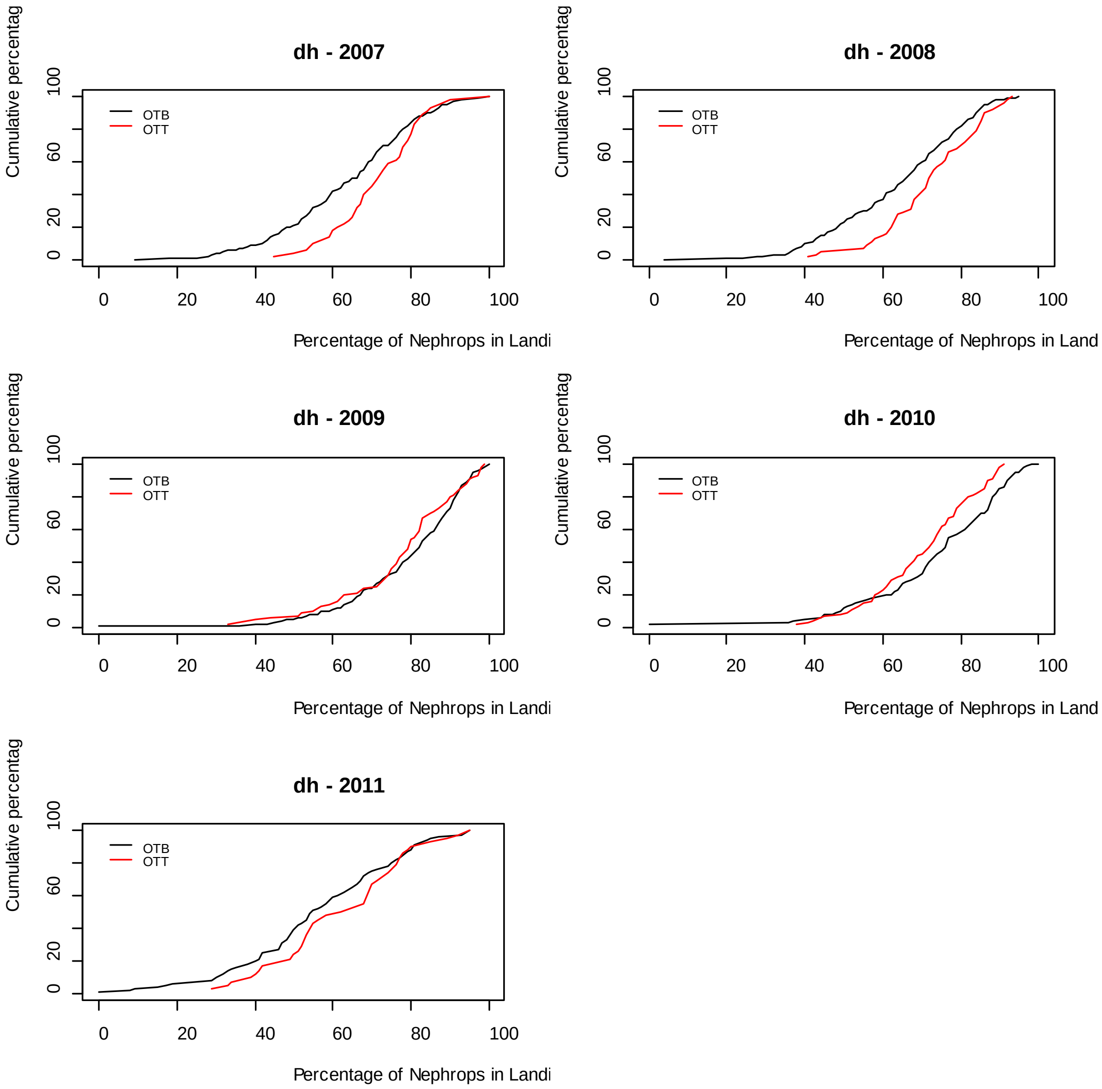


Figure 7.3.3. Cumulative percentage of trips vs. percentage of *Nephrops* in trip landing from log-book data associated with VMS pings from Devil's Hole, FU 34.

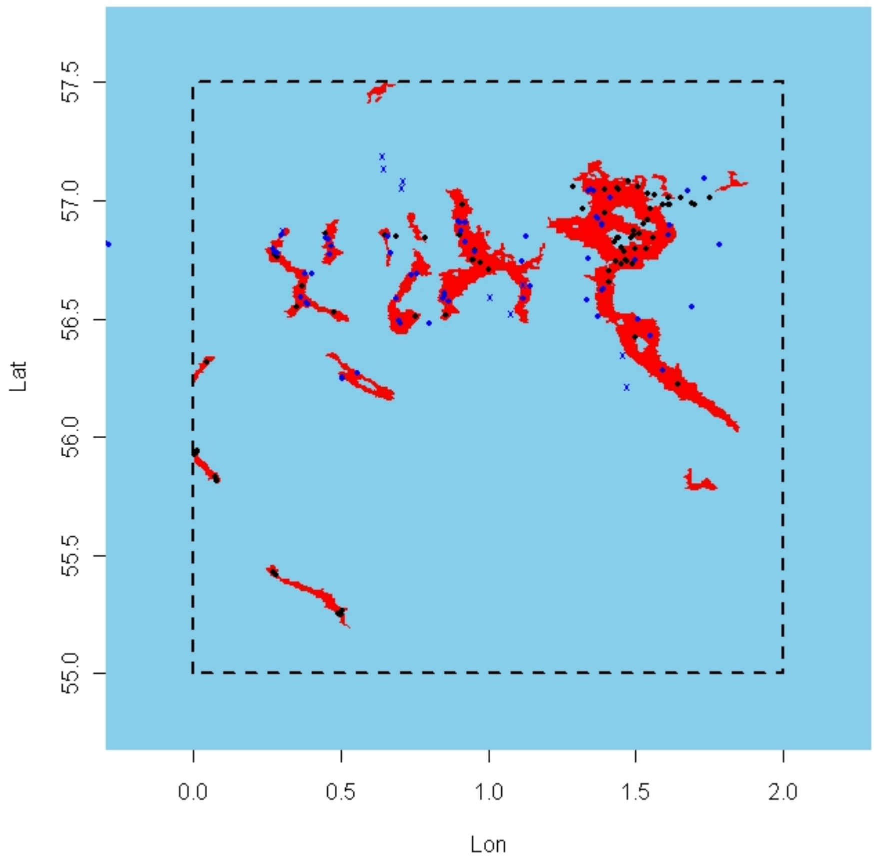


Figure 7.3.4. Location of hauls from observer trips (black) and UWTV survey stations (blue) compared to VMS polygon. Observations encountering zero *Nephrops* or *Nephrops* burrows are shown with a cross.

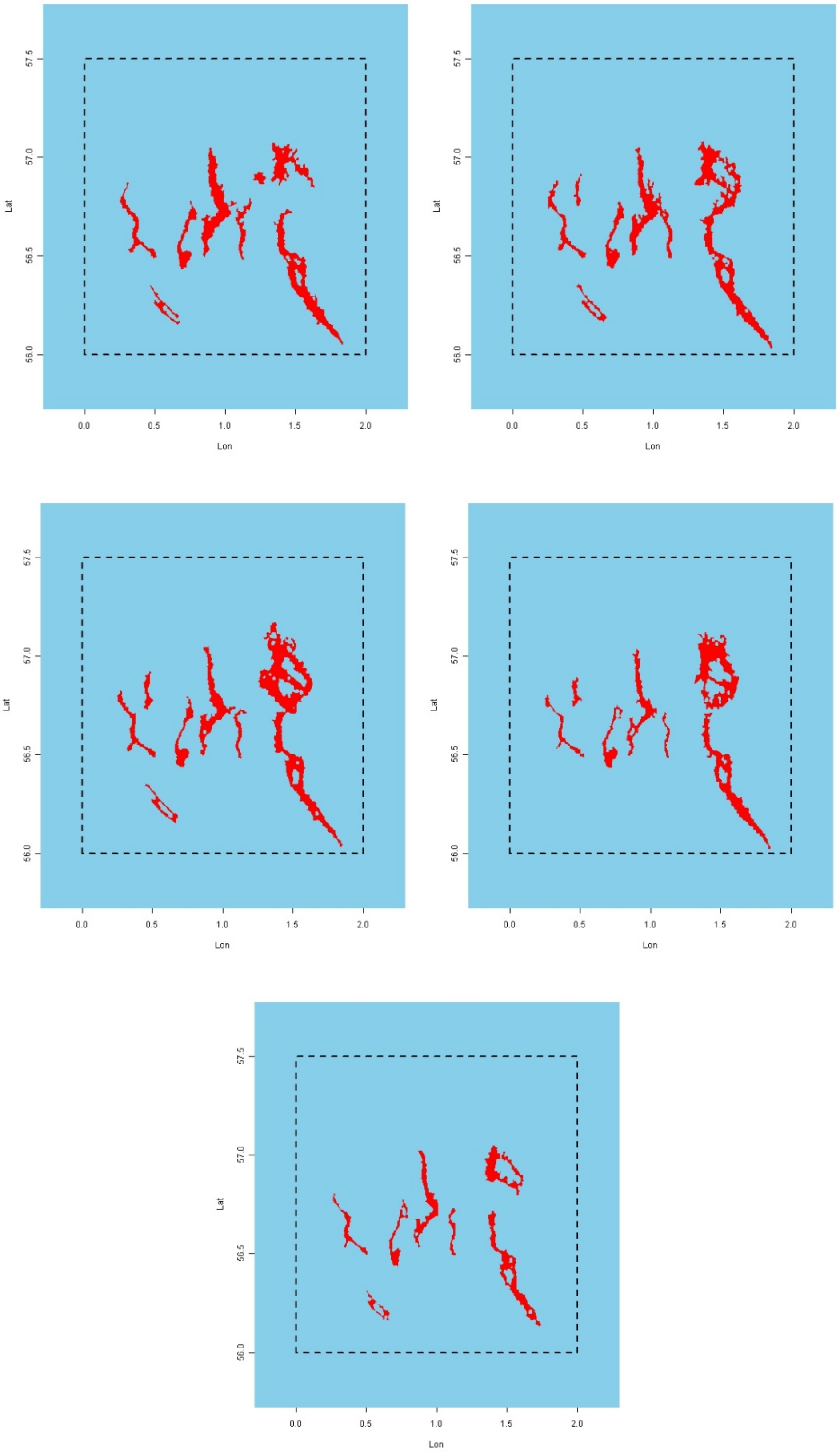


Figure 7.3.5. Polygons estimated by alpha convex hulls from *Nephrops* VMS data (2007–2011).

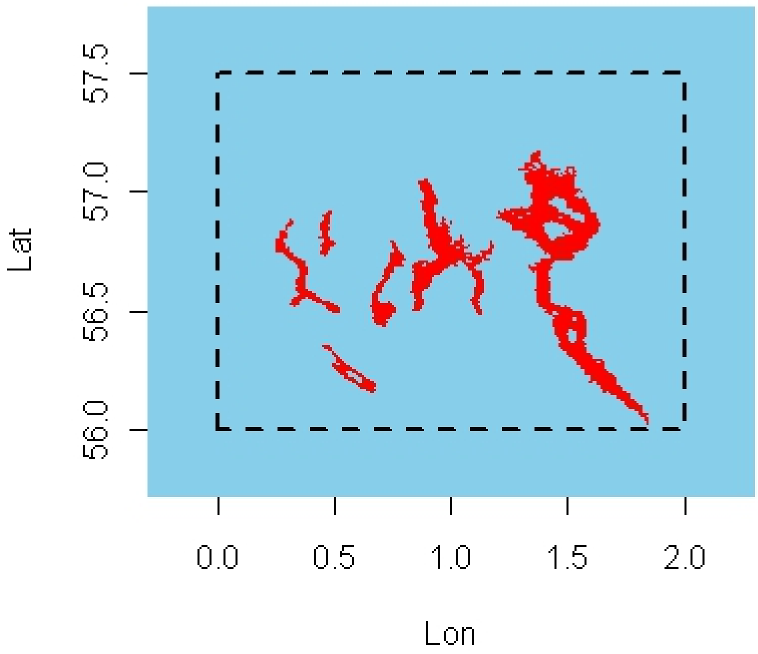


Figure 7.3.6. Union of 2007–2011 annual VMS polygons (from alpha convex hull) with VMS data filtered for *Nephrops* landings >30% of total, speeds of 0.5–3.8 knots and mesh size 70–99 mm.

7.4 Stock assessment methods

WK*NEPH* concluded that for the time being, advice should be provided for *Nephrops* in FU34 on the basis of the data limited approach (see Section 7.5 below). This can provide an indication of the level of medium-term average F in relation to F_{MSY} (borrowed from neighbouring stocks with similar characteristics) and this may also provide guidance on the level of abundance relative to MSY $B_{trigger}$.

In terms of stock trends, there are currently insufficient length–frequency data for use in constructing indicators. There is a commercial lpue series extending back to 2000 which should be used (with caution) to monitor stock trends.

7.5 Short-term forecasts, and how the advice is derived

WK*NEPH* concluded that for the time being, advice should be provided for *Nephrops* in FU34 on the basis of the data-limited approach.

Input data required: Recent absolute (bias corrected) density estimate from UWTV survey

In the range 0.2–0.3 m^{-2} but should account for the most recent estimates if different

Spatial extent

1753 km^2

Landings mean weight

31.76 g (average 2007–2010)

Discard rate in number

12.9% (average annual rate 2008–2011)

Discard survival

0%

Model and software: See spreadsheet derived at WGNSSK 2012 ('FINAL version of Nep-IV nonTVstocks included in advice.xls'; note that the formula used for the 2012 advice is wrong). Steps in formulating the data-limited table:

1) Use absolute density and spatial extent to derive *Nephrops* abundance for a range of densities (see above);
2) Convert potential landings weight into numbers using landings mean weight for a range of total landings (ten year average, half of ten year average, maximum of time-series);
3) Convert landings numbers into total removals by dividing by (1-discard rate in number);
4) Divide total removals (from 3) by *Nephrops* abundance (from 1) to obtain a matrix of harvest rates which can be compared to F_{MSY}.

7.6 Biological reference points , reasoning behind choice of recommended exploitation level

No specific reference points have been derived for this functional unit yet due to lack of sufficient length–frequency data to derive the inputs to per-recruit analysis. In the *Nephrops* data-limited approach the estimated harvest rate is compared to F_{MSY} harvest rates from neighbouring FUs which are likely to have similar characteristics. The range of F_{MSY} harvest rates for North Sea *Nephrops* is 8–16%.

7.7 Recommendations on the procedure for assessment updates and further work

Although progress has been made on the assessment and advice process for Devil's Hole *Nephrops*, there are still a number of outstanding issues that need to be addressed before this FU can be moved to full UWTV survey category. The workshop concluded that the aim should be to move to this approach in the near future once progress has been made on these major issues:

- Improved length–frequency information for use full *Nephrops* UWTV approach is required. This could be obtained in collaboration with the fish processing sector, potentially making use of commercial grade information recorded at processing factories to augment the landings samples currently collected by MSS staff. This would require sampling of the grades and the ability to identify the grade structure to trip level, but has the potential to provide an accurate reconstruction of the landings length structure. This approach should be investigated by MSS staff.
- In order to improve the precision of UWTV survey density estimates from this area, it is recommended that the survey should aim to increase the number of stations conducted with sufficient geographical spread to cover the individual mud patches. In 2010, 20 stations were surveyed which re-

sulted in a CV of 17%, so potentially this could be used as a target for future surveys. This could potentially be accomplished by a redistribution of survey effort; by making small reductions in the number of survey stations carried out in, for example, the Clyde and Sound of Jura.

7.8 References

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8 FU 32 Norwegian deep

8.1 Current assessment and issues with data and assessment

Nephrops in FU 32 was considered to belong to category 6 (data-limited stocks) by WKLIFE (WGNSSK 2012). Category 6 stocks include stocks for which only landings data are available. Danish effort and landings have decreased in recent years, and the Norwegian fishery is very small (Figure 8.1). Thus the stock is probably underexploited. Due to the low economic importance, it is unlikely that an UWTV survey will be established in the near future.

The perception of the *Nephrops* stock in FU 32 is based on indicators (Danish landings and effort data and mean sizes in catches and landings) (Figure 8.1). The overall trend in the lpue figures indicates a stock fluctuating without trend since the mid-1990s. The trends in mean size in landings and catches, and overall size distribution in the catches (Figures 8.2.1.2, 8.2.1.3) also indicate that the stock is not overexploited. The management regime in the Norwegian zone of the North Sea was changed in 2002, with mesh size in large mesh demersal trawls being increased to 120 mm. One should think this would have resulted in a lower lpue, but this seems not to be the case. Similarly, one should expect lpue indices to increase following the recent decrease in Danish landings. But this does not seem to be the case either (Figure 8.1.1).

The assessment of the *Nephrops* stock in FU 32 has since 2012 been based on a new approach outlined by WGNSSK (WGNSSK 2012), where a range of estimated biomasses were used to consider different harvest rates. The area of the *Nephrops* grounds was estimated to provide a likely envelope for the total abundance of *Nephrops* in FU 32, using UWTV-survey information on the mean density of *Nephrops* (minimum value of 0.1 animals/m^2) from the neighbouring functional unit (FU 7 Fladen Ground), together with the mean discard percentage in Danish catches in the period 2003–2012, and mean weight of *Nephrops* in Danish catches in 2012. The area of the *Nephrops* grounds in FU 32 was estimated using information on the spatial distribution of the Norwegian and Danish fisheries, as well as suitable sediment. The biomass estimates imply very low harvest rates in FU 32 (≤1%), even in former years with high landings (1000–1200 t).

The main goal of the 2013 benchmark of FU 32 *Nephrops* was to scrutinize all available data, in particular Norwegian survey and logbook data and Danish observer data, to see if more information could be extracted from already existing data sources.

The working document prepared for the 2013 WK*NEPH* meeting reported on the following:

- Stock definition;
- *Nephrops* data from the Norwegian annual shrimp survey covering ICES Division IIIa and Subdivision IVaE;
- Norwegian effort and landings data;
- Catch sampling data.

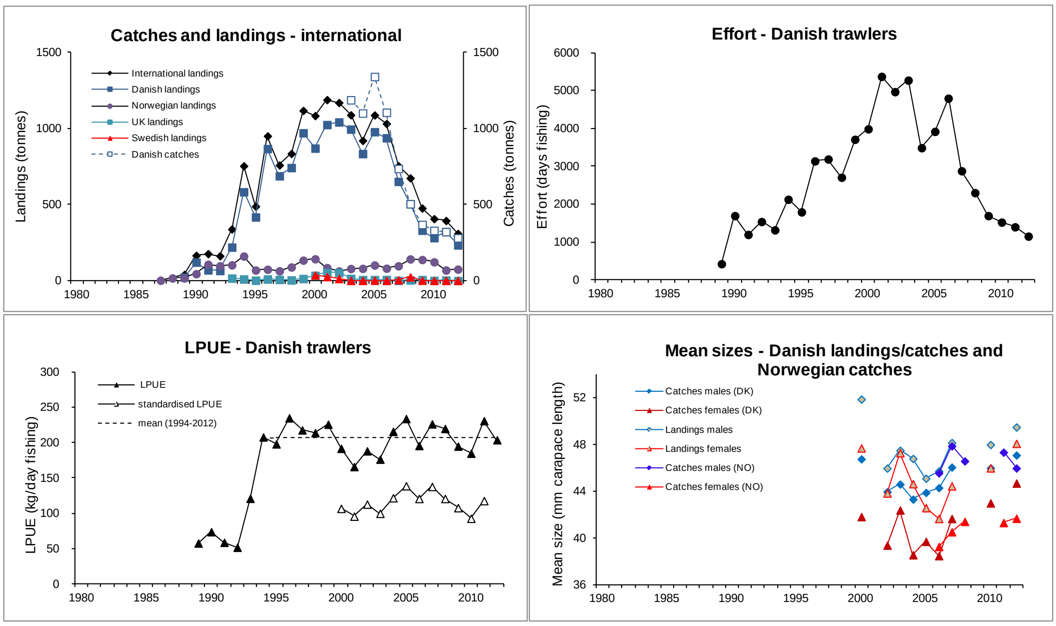


Figure 8.1. Long-term trends in *Nephrops* fishery statistics from FU 32: international landings and Danish catches, Danish effort and lpue, and mean sizes in catches and landings (Norwegian and Danish data).

8.2 Compilation of available data

8.2.1 Catch and landings data, incl. selection-at-length (see also Section 8.2.4)

Catch sampling

Denmark has had on-board observers on commercial fishing vessels operating in FU 32 since 1997 (Table 8.2.1.1). Both the landings and discard components of the catch are sampled as part of this at-sea-sampling programme. *Nephrops* are length measured and determined to sex (in 2009 females and males were pooled). The data are used for estimating the discard proportion of the Danish catches, and they provide length data (length–frequency distributions and mean length per sex in landings and catches). In 2011, the Danish at-sea-sampling programme was changed, with observer trips being randomly drawn from all Danish fishing trips. The low chance of selecting the few fishing trips in FU 32 resulted in only one observer trip in this functional unit in 2011. The at-sea-sampling programme was changed again in 2012, resulting in a satisfactory number of observer trips, as in previous years. WK*NEPH* recommends that these observer data should be used to obtain biological information about the stock: maturity data (see Section 8.2.2), weight-at-length relationships, and seasonal sex ratios (Figure 8.2.1.1). Sex ratios can be obtained from existing data, while the extra work involved in obtaining maturity and weight-at-length data must be clarified with observers. WK*NEPH* further recommends that the standard figure with mean lengths in landings and catches (Figure 8.1) should include mean lengths in discards as well, and data prior to 2000 should be included in the figure. The amount of discards can be used as a proxy for recruitment, with a decreasing mean size indicating an increasing amount of small animals in the population.

Danish discard data back to 2003 have been provided to the working group (Table 8.2.1.2). The mean discard percentage (discard as percentage of total catch) (2003–2012) is 17.0%, while the mean discard percentage for the last three years (2009, 2010,

2012) is 13.9%. The annual Danish discard-to-landings ratios are considered unsuitable for estimating Norwegian discards as the fisheries in the two countries take place partially on different fishing grounds (Figures 8.2.4.7, 8.2.4.8) and by different gears (see stock annex A.2). WK*NEPH* recommends that discard data back to 1997 be made available to the working group.

The Norwegian coast guard has provided length measurements of commercial *Nephrops* catches from inspections of mainly Danish trawlers back to 2005 (Table 8.2.1.3). The total catch is sampled, thus these data cannot be used to estimate discards. The coast guard tends to measure catches by total length (TL). There were no CL data in 2010 and very limited CL data in 2005 and 2009. Since TL is measured in cm, these data cannot be converted to CL without losing precision. The coast guard has been made aware of this.

Annual length–frequency distributions of catches from the at-sea-sampling programme and coast guard samples (Figures 8.2.1.2, 8.2.1.3) indicate that there are relatively few specimens <40 mm (MLS) and therefore little discard in FU 32 compared with FU 3 and 4, where MLS is also 40 mm. The length–frequency distributions were smoothed in 2013, following the recommendation of WK*NEPH*.

Table 8.2.1.1. Danish at-sea-sampling programme in FU 32: Annual number of observer trips, total number of hauls, and total number of *Nephrops* in samples of discards and landings. No data were obtained in 1999 and 2001.

Year	Number of trips	Number of hauls	Number of *Nephrops* in discard sample	Number of *Nephrops* in landings sample
1997	4	31	5228	41
1998	1	2	0	204
1999				
2000	2	20	146	3760
2001				
2002	5	38	1849	3125
2003	3	27	2617	3344
2004	5	28	2619	3484
2005	3	23	1565	2108
2006	5	17	1498	2169
2007	6	25	1746	2690
2008	8	45	2492	5489
2009	5	19	598	2030
2010	6	21	1122	2466
2011	1	5	0	384
2012	5	20	1369	2976

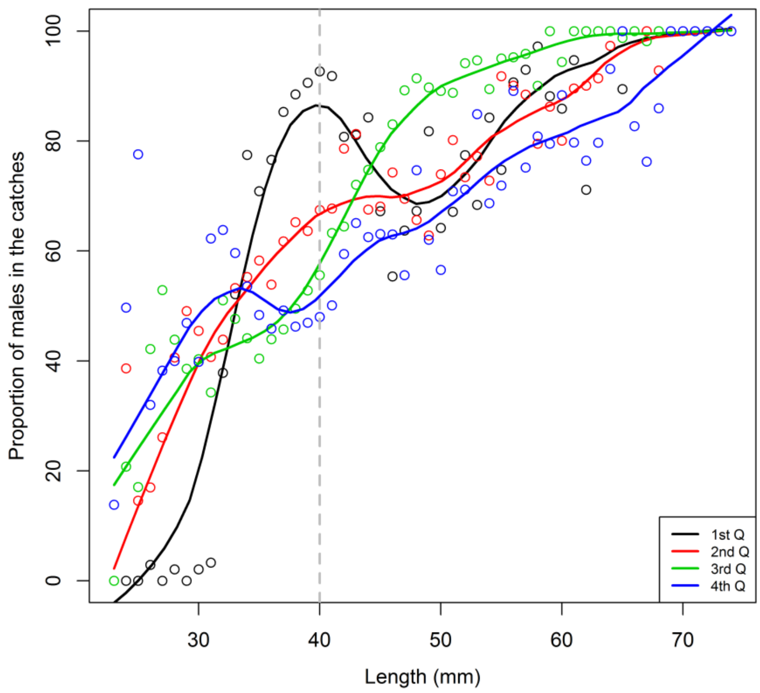


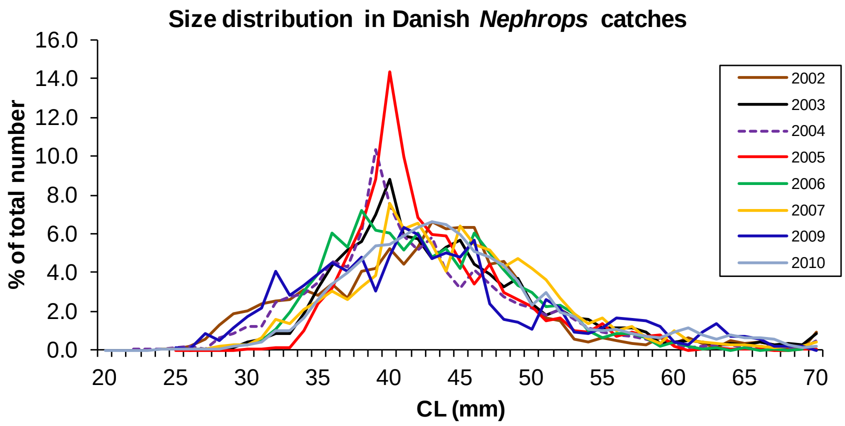
Figure 8.2.1.1. Proportion of males in Danish catches per length and quarter. The dotted, vertical line indicate the minimum legal size (MLS) of 40 mm.

Table 8.2.1.2. Danish landings (tons), discards (tons) and discards as percentage of total catch in 2003–2012.

YEAR	DANISH LANDINGS	DANISH DISCARDS	DANISH DISCARD %
2003	996	193	16.2
2004	835	267	24.2
2005	979	363	27.0
2006	939	168	15.2
2007	652	85	11.5
2008	505		
2009	331	38	10.3
2010	282	48	14.5
2011	322		
2012	234	47	16.7

Table 8.2.1.3. Inspection of commercial trawlers (with *Nephrops* in the catch) in FU 32 by the Norwegian coast guard: Annual number of inspections (samples), and total number of *Nephrops* in the catch samples. No data were obtained in 2010.

Year	Number of samples	Number of *Nephrops* in samples
2005	1	118
2006	11	1399
2007	9	1345
2008	10	1462
2009	1	182
2010		
2011	12	1856
2012	4	401



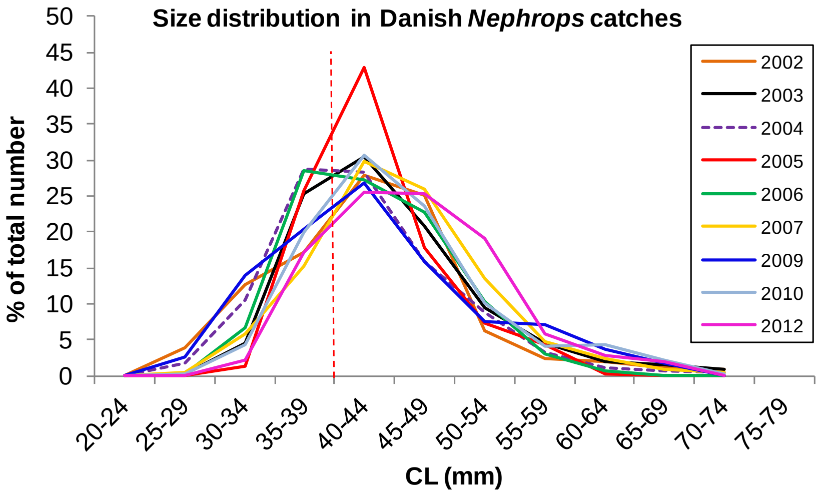


Figure 8.2.1.2. Annual length–frequency distributions of Danish catches from the Danish at-sea-sampling programme. The dotted, vertical line indicates the minimum legal size (MLS) of 40 mm. Data presented by whole mm (upper figure, until 2012), and by 5 mm length groups (lower figure, from 2013 onwards).

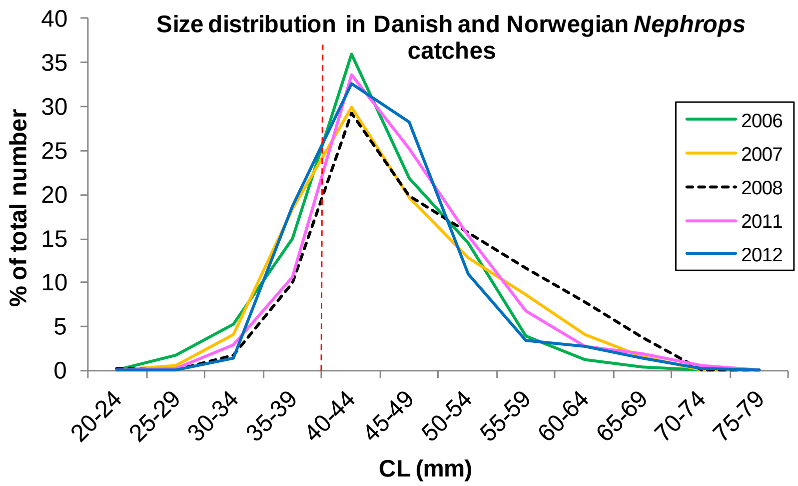


Figure 8.2.1.3. Annual length–frequency distributions of Danish and Norwegian catches from inspections by the Norwegian coast guard. The dotted, vertical line indicates the minimum legal size (MLS) of 40 mm. Data presented by 5 mm length groups (from 2013 onwards).

8.2.2 Biological data (Growth, maturity, natural mortality)

Maturity

Maturity stage has since 2006 been checked and determined for all females sampled at the annual Norwegian shrimp survey (Table 8.2.3.1). A female is considered sexually mature when the ovary is green (Figure 8.2.2.1). Data from all years were pooled as too few females are sampled each year. Size at maturity is determined to 28 mm (Figure 8.2.2.2), which is higher than for most other *Nephrops* stocks in the North Sea (WGNSSK 2012). However, as *Nephrops* data from the shrimp survey are limited, WK*NEPH* recommends that maturity data are collected by the Danish at-sea-sampling programme (see Section 8.2.1), where annual maturity estimates should be obtainable.

At the Norwegian shrimp survey in 2013, appendices masculinae were collected from all males (Figure 8.2.2.3). The survey trawl has a mesh size of 20 mm and a 6 mm inner lining net, but still few small males were collected. The current data cannot be used for determining size at sexual maturity for males, and it should be considered whether such data also can be collected by the Danish at-sea-sampling programme.

Figure 8.2.2.1. Mature females. The green ovaries are visible through the shell of the tails.

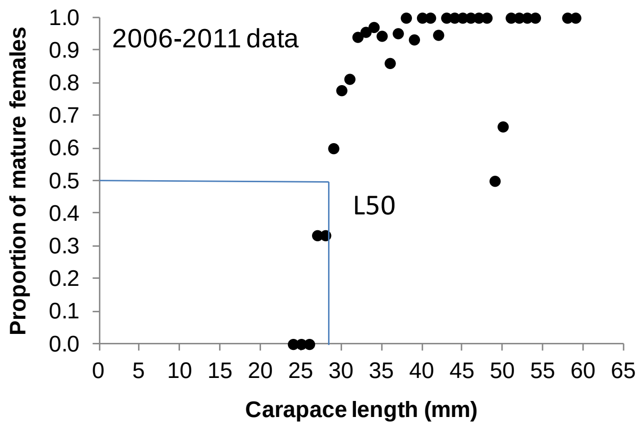


Figure 8.2.2.2. Proportion of mature females by carapace length. Pooled data (2006–2011) from the Norwegian annual shrimp survey. Size at maturity is determined to 28 mm.

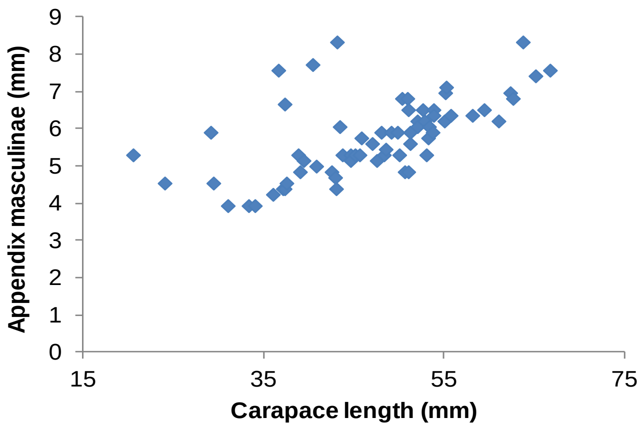


Figure 8.2.2.3. Length of appendix masculinae by carapace length for males sampled at the Norwegian annual shrimp survey in 2013.

8.2.3 Survey data

A trawl survey for northern shrimp in Skagerrak and the Norwegian Deep (ICES Division IIIa and Subdivision IVa east) has been conducted annually by the Norwegian Institute of Marine Research (IMR) since 1984. The survey data consist of: 1) one time-series based on a survey conducted in October/November 1984–2002 using RV *Michael Sars* and the Campelen-trawl; 2) a point estimate for 2003 as RV *Michael Sars* was taken out of service and substituted with RV *Håkon Mosby*, whose winches at that time were not powerful enough for the Campelen-trawl, resulting in the survey being conducted with the Shrimp trawl 1420; 3) a start of a potential new time-series as the survey in both 2004 and 2005 was conducted in May/June with RV *Håkon Mosby* using the standard Campelen trawl; and 4) a start of yet a new time-series in February 2006 still using RV *Håkon Mosby* and the Campelen trawl. Since 2006 the survey has been conducted in January/February as the first quarter is the optimal time for surveying the shrimp stock, giving good estimates of recruitment and berried females.

Survey design

The survey is stratified by four depth zones (100–200 m, 200–300 m, 300–500 m, and >500 m), and area (Figure 8.2.3.1), and has a fixed station design, assuming that the temporal variation in the shrimp and fish stocks generates the necessary randomness. The hundred stations trawled in 2000 were defined as fixed stations for future surveys. In 2008 thirteen more stations (positions from survey reports in 1984–1996) were added to obtain a better coverage of the area (Figure 8.2.3.1). Ideally, all stations should be trawled every year, giving a coverage of one haul per 142 nm^2. However, this rarely happens due to time and weather constraints.

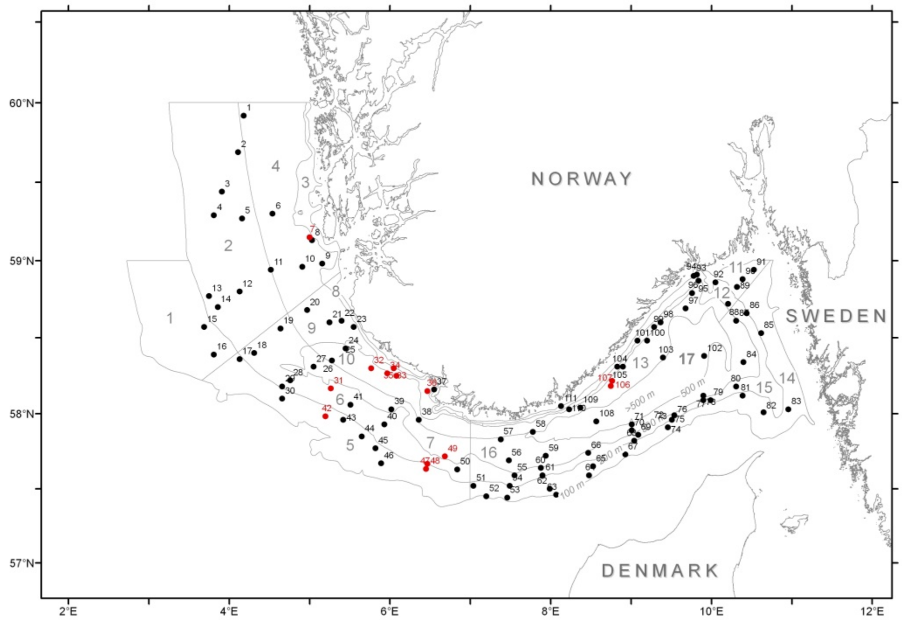


Figure 8.2.3.1. The Norwegian annual shrimp survey in the Norwegian Deep (FU 32) and Skagerrak (FU 3): survey area with strata 1–17 and fixed stations. Stations marked in red were added in 2008 (see text).

The survey trawl used is a Campelen 1800/35 bottom trawl with rock-hopper gear. Mesh size in the codend is 20 mm with a 6 mm inner lining net. Tow duration was one hour until 1989 when it was reduced to 0.5 hour. Tow speed is roughly 3 knots. Strapping (a 10 m rope 200 m in front of the doors) was introduced in 2008 to ensure fixed trawl geometry (door spread of 46–47 m).

Recording of *Nephrops*

Recording of *Nephrops* was irregular in the years 1984–1996 (Table 8.2.3.1). In 1997 specific investigations of *Nephrops* were initiated, with some stations trawled with *Nephrops* trawl (70 mm codend) (Figure 8.2.3.2). Animals were length measured and sexed. Survey reports note that catches were highly dependent on the time of day. Trawling with the *Nephrops* trawl was discontinued in 2002, and only tried again in 2009 (Figure 8.2.3.3). From 2006 onwards all *Nephrops* in the Campelen trawl have routinely been length measured and sexed, and the maturity stage of females has been determined. In 2013 appendix masculinae was collected from all males to determine size at maturity.

The number of trawl stations in FU 32 (total of *Nephrops* and Campelen trawl stations) where *Nephrops* have been recorded (1997–2012) have varied between eight and 31 (Table 8.2.3.1). The number of *Nephrops* per trawl haul has varied substantially, between one and 617 in the Campelen, and between one and 1474 in the *Nephrops* trawl (Table 8.2.3.2).

Table 8.2.3.1. Number of trawl stations in the Norwegian shrimp survey in FU 32 where *Nephrops* was recorded, and total number of *Nephrops*, by trawl type (Campelen (C), *Nephrops* (N) and shrimp trawl(s)) and year.

	ST (C)	ST (N)	ST (S)	NO (C)	NO (N)	NO (S)	LENGTH	SEX	STAGE
1984	1								
1985									
1986									
1987	3			9					
1988									
1989									
1990	1			50					
1991									
1992									
1993	5			35					
1994	4			90			x	x	
1995	2			72			x	x	
1996	1			7					
1997	10	7		101	1955		x	x	
1998	8	2		107	258		x	x	
1999	11	6		392	2939		x	x	
2000	14	4		137	370		x	x	
2001	10	6		638	1808		x	x	
2002	10			1500					
2003			6			61			
2004	20			1081					
2005	25			515			x	x	
2006	8			277			x	x	x
2007	19			445			x	x	x
2008	15			69			x	x	x
2009	18	7		82	59		x	x	x
2010	22			152			x	x	x
2011	31			247			x	x	x
2012	12			80			x	x	x
2013							x	x	x

No *Nephrops* recorded in 1985, 1986, 1988, 1989, 1991, and 1992.

Missing information on number in catch in 1984, 1993, 2004, 2005, and 2008.

Missing information on total weight of catch in 1987, 1990, 2009, and 2010.

Missing information on lengths in 1997, 1998, 2005, 2008, 2009.

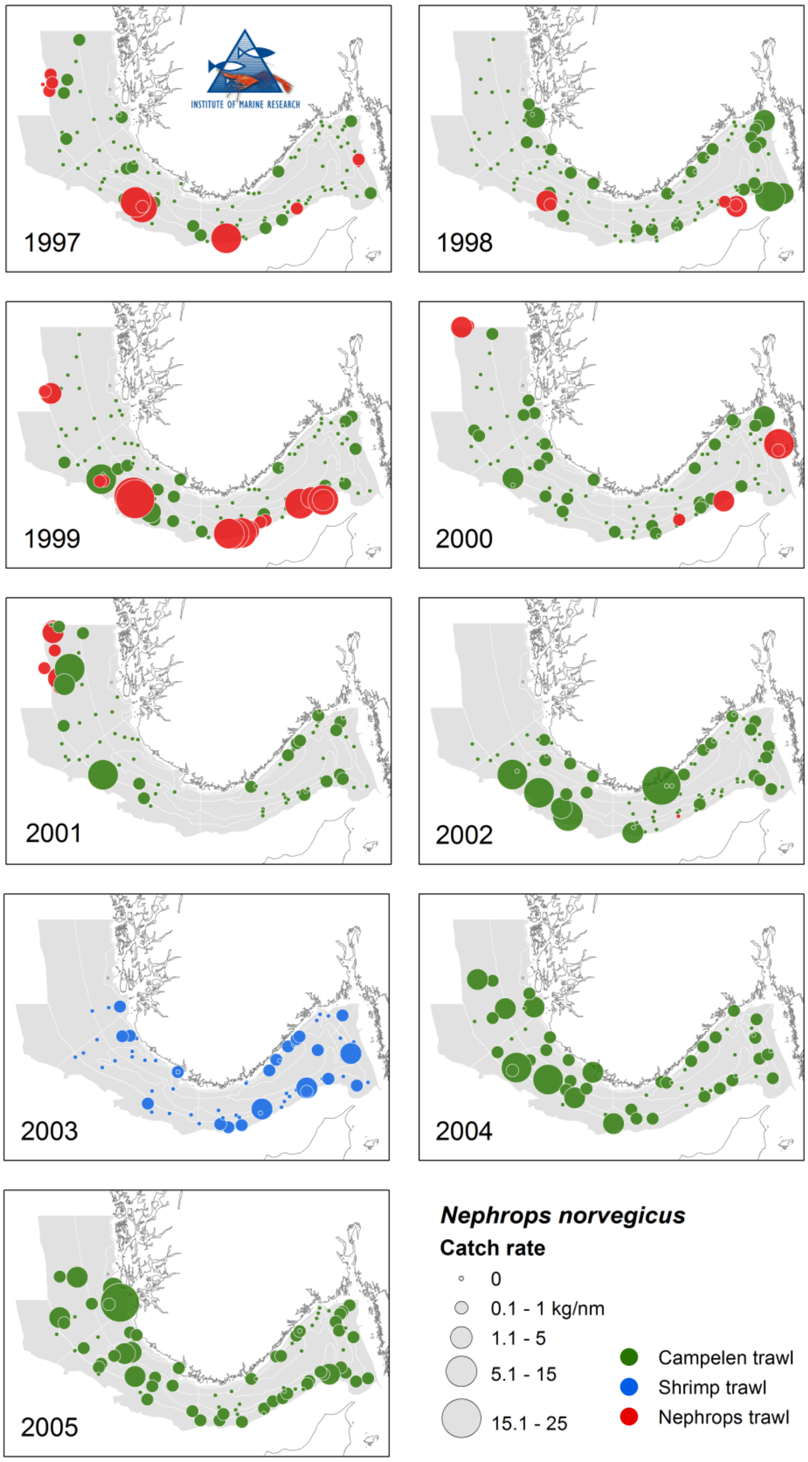


Figure 8.2.3.2. Catches (kg/nm trawled) of *Nephrops* per trawl type from the Norwegian shrimp survey in the Norwegian Deep (FU 32) and Skagerrak (FU 3), October/November 1997–2003, and June 2004–2005.

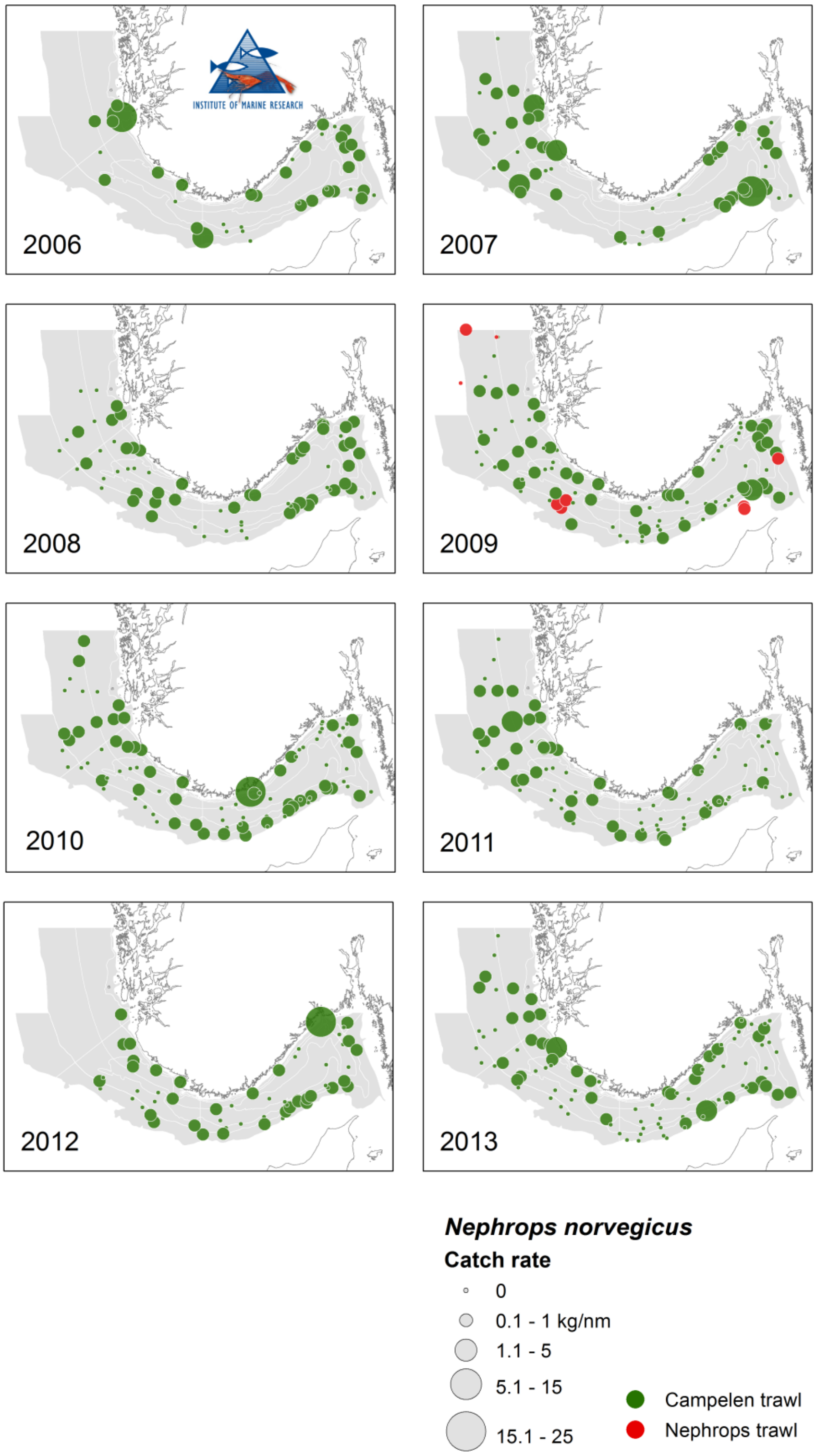


Figure 8.2.3.3. Catches (kg/nm trawled) of *Nephrops* per trawl type from the Norwegian shrimp survey in the Norwegian Deep (FU 32) and Skagerrak (FU 3), January/February 2006–2013.

Table 8.2.3.2. Number of *Nephrops* recorded per trawl station (given for Campelen (C) and *Nephrops* (N) trawls separately) and year. Blue cells denote stations where only weight of *Nephrops* was recorded.

	ST	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
N.trawl	1	117	202	1474	62	169								24			
	2	81	56	1215	10	828								1			
	3	89		93	7	12								1			
	4	7		21	291	102								16			
	5	696		127		568								10			
	6	789		9		129								6			
	7	176												1			
C.trawl	1	1	3	7	16	25	4	*1*		1	5	4	1	11	1	5	7
	2	6	7	10	24	3	7	*5*	66		1	14	1	1	16	1	27
	3	1	9	16	3	128	2	*13*	2	81	22	3	2	1	5	1	4
	4	4	2	2	3	90	84	*12*	3	43	3	129	11	5	1	6	2
	5	11	43	13	1	70	201	*14*	30		196	20	4	3	2	8	4
	6	3	1	13	7	48	2	*16*	7		35	3	3	1	1	10	7
	7	12	36	5	1	10	617			3	9	24	2	1	21	1	13
	8	5	6	304	1	240	581		268		6	2	25	1	2	1	6
	9	30		2	1	18	1		186			2		1	21	5	1
	10	28		3	1	6	1		54			2	10	2	9	4	4
	11			17	73				105			10	4	1	1	4	3
	12				4				87	22		35	2	1	6	45	2
	13				1				21	8		4	2	1	32	2	

ST	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
14				1				81	108		109	1	2	1	1	
15								34	51		2	1	17	3	1	
16								30	10		1		16	1	2	
17								1	5		74		6	12	2	
18								90	8		5		11	8	56	
19								6	65		2			2	1	
20								10	10					1	2	
21									16					3	4	
22									51					3	9	
23									4						18	
24									4						2	
25									25						4	
26															2	
27															6	
28															13	
29															22	
30															7	
31															2	

Biomass index

Due to the large variation in the number of *Nephrops* per trawl haul, and the diurnal variation in catch rate, the survey data have been considered unsuitable for calculating biomass indices of *Nephrops*. WK*NEPH* nevertheless suggests that these survey data should be explored further.

Length distributions 2006–2012

Yearly catches of *Nephrops* (both males and females) in FU 32 in the years 2006–2012 have varied between 69 and 445. Annual length–frequency distributions (Figure 8.2.3.4) indicate that the relative frequency of larger animals has increased after 2007. The length–frequency distributions in FU 32 and FU 3 (Skagerrak) are similar (Figure 8.2.3.5). The numbers of *Nephrops* caught in the Campelen trawl are few. WK*NEPH* recommends that annual length–frequency distributions from the Danish at-sea-sampling programme are used.

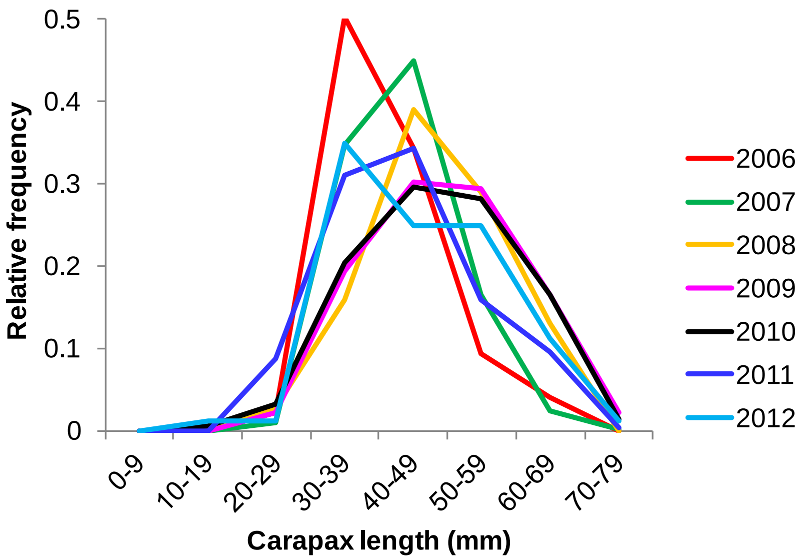


Figure 8.2.3.4. Annual length–frequency distributions (relative frequency) of *Nephrops* (males and females) in FU 32 from the Norwegian shrimp survey, 2006–2012. Sample sizes of *Nephrops* (n): (2006–2012): 277, 445, 69, 139, 152, 239, 80.

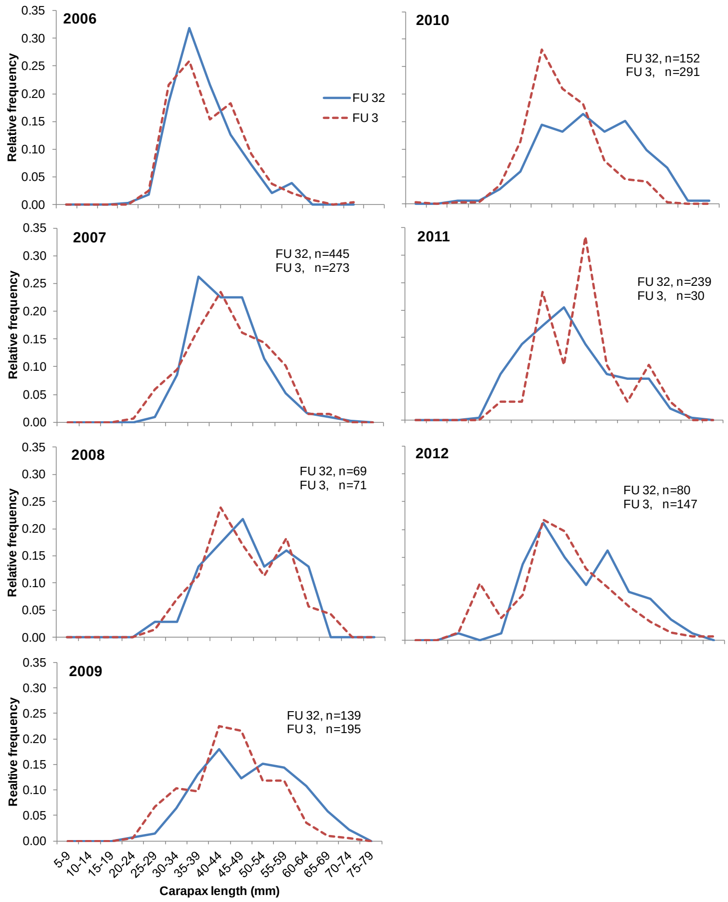


Figure 8.2.3.5. Annual length–frequency distributions (relative frequency) of *Nephrops* in FU 32 compared with *Nephrops* in FU 3 (Skagerrak), 2006–2012. Sample sizes are given in the figure.

8.2.4 Commercial data (lpue etc.)

Danish lpue data

See stock annex.

Norwegian lpue data

Norwegian logbooks are available back to 1980. In 2000 the format was changed with the introduction of more detailed information. From 2000 to 2010 catches (kg) have been given per vessel per day, with information on the number and duration of hauls that day, main gear (bottom, shrimp, *Nephrops* and twin trawls are used in the *Nephrops* fishery), mesh size, and location of hauls (ICES statistical square). Electronic logbooks compulsory for all vessels ≥15 m were introduced in 2011. The electronic logbooks have a better resolution of the data, with catches given per haul, and with information on haul position and both type and number of gear utilized. The target species and the species comprising the bulk of the catch (not always the same) are also given. However, in 2011–2012 information on mesh size is lacking. Mesh size was reintroduced in the logbooks in 2013.

The information on *Nephrops* in Norwegian logbooks is deficient. Logbook catches from FU 32 constitute from 12 to 40% of the total landings in 2000–2012 (Table 8.2.4.1). Logbooks contain only information from trawl hauls, not traps. Considering only landings from trawls, the logbooks constitute 17–59% of these landings in 2000–

2012. In 2009, only about 600 kg of *Nephrops* catches were recorded in the logbooks, constituting only 1% of the trawl landings this year. The reason for this is not known. In 2011–2012 the logbook catches made up 56–59% of the trawl landings. However, as a major portion of the Norwegian fleet landing *Nephrops* in FU 32 consists of vessels <15 m, especially north of 60°N, even the compulsory electronic logbooks do not cover the whole trawl fleet. The growing Norwegian trap fishery is also not covered by logbooks.

Table 8.2.4.1. *Nephrops* in FU 32: total Norwegian landings; total Norwegian landings from trawl gears; Norwegian catches recorded in logbooks; and the percentage of Norwegian landings (total and from trawl gears) covered by logbooks, in 2000–2012.

YEAR	RECORDED LANDINGS TOTAL	RECORDED LANDINGS TRAWL	CATCHES IN LOGBOOKS TRAWL	% LANDINGS, TOTAL	% LANDINGS, TRAWL
2000	143	143	58	41	41
2001	85	72	12	14	17
2002	63	42	9	14	21
2003	79	68	28	35	41
2004	80	72	31	39	43
2005	102	89	41	40	46
2006	81	62	19	23	31
2007	97	77	23	24	30
2008	142	112	21	15	19
2009	138	107	0.6	0	1
2010	123	82	15	12	18
2011	70	29	17	24	59
2012	75	25	14	19	56

The use of the various gear codes is inconsistent, both between years as well as between the landing statistics and the logbooks. For instance, there are no records on the use of *Nephrops* trawls in the 2006–2012 logbooks, while a substantial part of the landings in the same time period are recorded as caught by *Nephrops* trawl. Bottom and *Nephrops* trawls, as well as bottom and shrimp trawls, seem to some degree to be used interchangeable in the logbooks, irrespective of the actual gear being used (Figure 8.2.4.7). Bottom and shrimp trawls can be distinguished based on mesh size, however, this was not possible in 2011–2012 due to lack of information on mesh size. Thus, target species was considered. If the target species is shrimp, it is probably safe to assume that the gear in use is a shrimp trawl, and similarly, if the target species is *Nephrops* or demersal fish one can assume that the gear in use is a large mesh demersal trawl. Twin shrimp trawl and twin demersal trawl (both recorded as "twin trawl" in 2000–2010) can be distinguished based on mesh size. However, there are reasons to believe that twin trawl has not always been correctly recorded (interviews with shrimp fishers).

Nephrops and demersal trawls

Logbook data from *Nephrops*, demersal, and twin trawls (large mesh size) combined are considered unsuitable for lpue analyses for several reasons. 1) Twin trawl cannot be included as a variable in a GLM standardization as it is not known if fishers have correctly recorded the use of this gear. 2) The amount of available data varies from year to year, with very few data in both 2009 and 2010 (Figure 8.2.4.1). 3) The number of vessels in the logbooks differs between years, with data from eleven vessels in 2000 and eight in 2002, but from only 1–5 vessels otherwise until 2010 (Figure 8.2.4.1). In 2011–2012, respectively seven and five vessels are found in the logbooks (target species demersal fish/*Nephrops*). 4) One particular vessel ("Vessel X") completely dominates the logbook data in the years 2003–2008. 5) The lpue time-series has a conspicuous peak in 2005–2007 which cannot reflect the state of the stock (Figure 8.2.4.2).

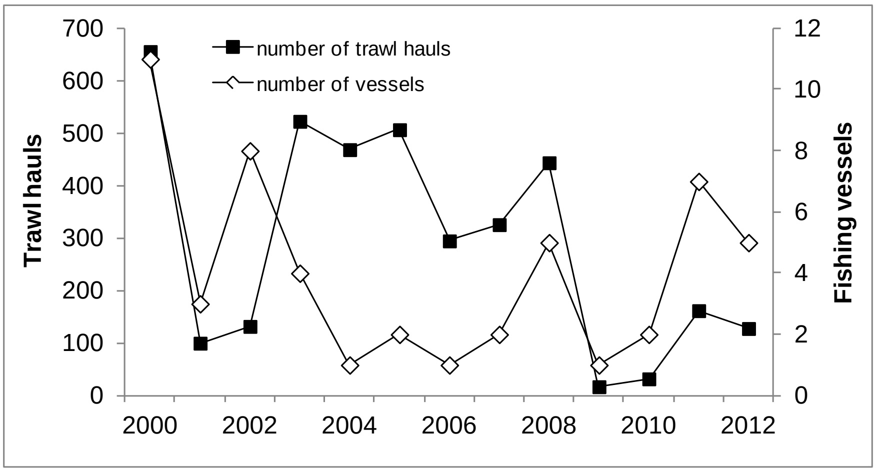


Figure 8.2.4.1. *Nephrops* in FU 32: Number of trawl hauls and number of vessels in Norwegian logbooks for large mesh gears (*Nephrops* and demersal trawls), 2000–2012. Electronic logbooks were introduced in 2011.

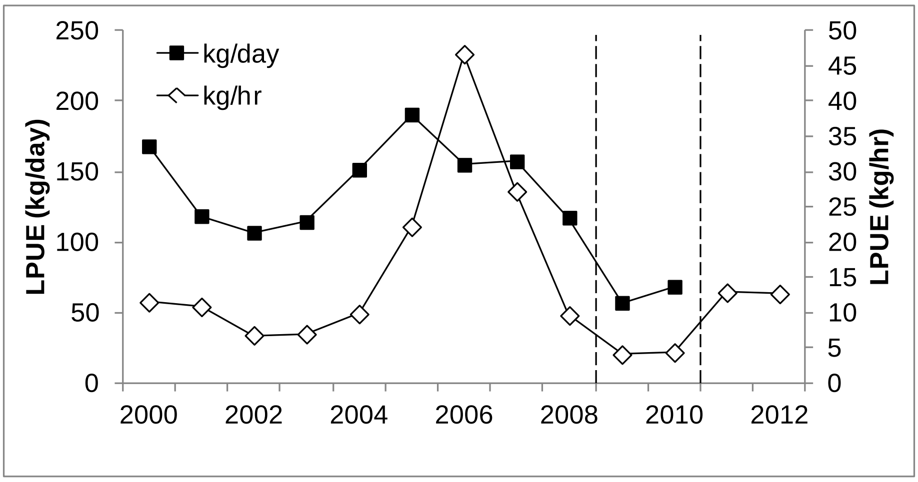


Figure 8.2.4.2. *Nephrops* in FU 32: lpue indices in kg/h and kg/day for large mesh gears (*Nephrops* and demersal trawls) from Norwegian logbooks, 2000–2012. The dashed vertical lines mark the two years with very limited data (2009–2010) and the two years with electronic logbooks (2011–2012).

Catches from "Vessel X" made up almost 100% of the logbook catches in 2003–2006 and between 70 and 90% of the catches in 2007–2008 (Figure 8.2.4.3). The elevated lpue indices in 2005–2007 are explained by strange recordings of haul duration by this vessel in these years (Figure 8.2.4.4). In 2005 most hauls lasted six hours or less, while in 2006 and 2007 most hauls lasted exactly three hours. This is in contrast to the other years when haul duration varied between one and 24 hours. Thus, lpue indices in kg/hr for 2005–2007 cannot be used.

Lpue indices in kg/day were also calculated (Figure 8.2.4.2). The 2000–2008 indices are within the range 100–200 kg/day, which is in good agreement with Danish lpue indices (range 150–250 kg/day in 1994–2012). The Norwegian lpue indices in kg/day in 2009–2010 are much lower, which could be due to very limited data these years. In 2011 and 2012 catch was given by haul, not day, and the per-haul data have not been converted to per-day data.

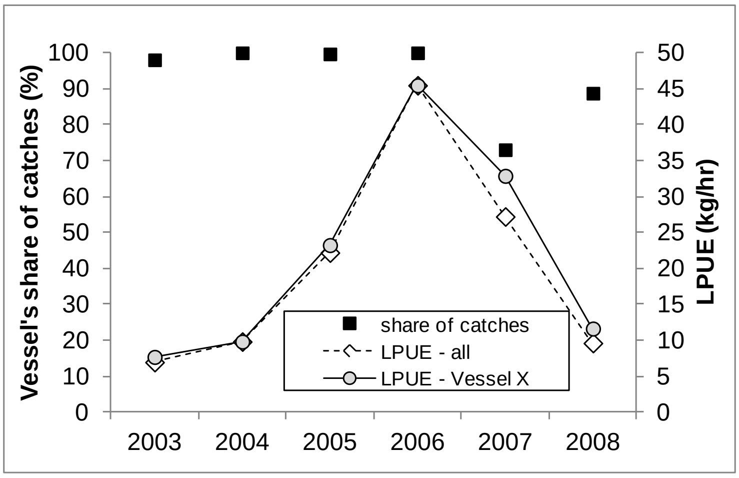


Figure 8.2.4.3. ***Nephrops*** **in FU 32: "Vessel X"'s share (%) of catches in the Norwegian logbooks, and vessel specific lpue indices for "Vessel X" compared with lpue indices for all vessels in the logbooks. "Vessel X" recorded catches in the logbooks from 2003 to 2008.**

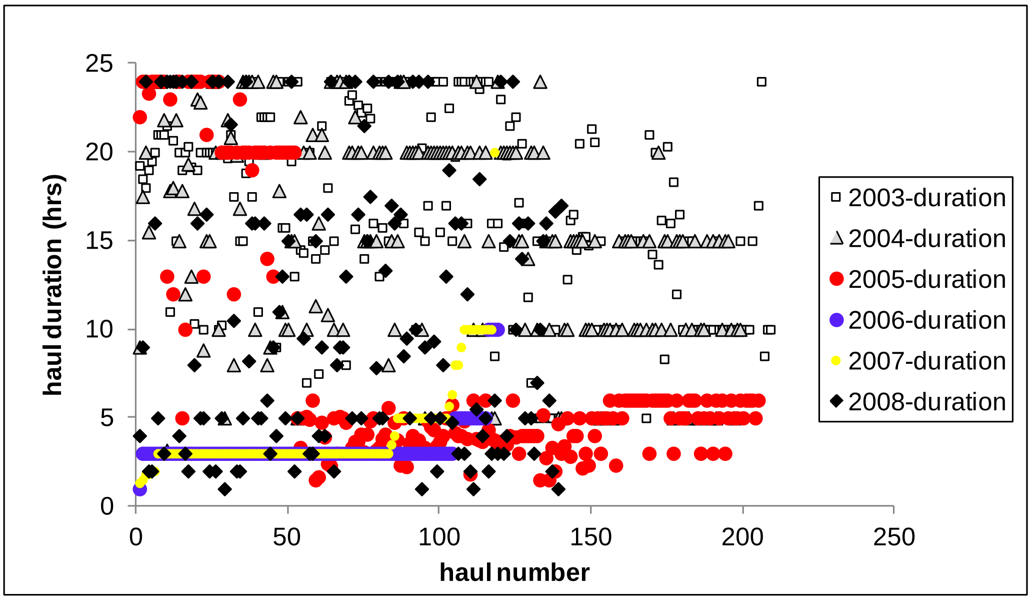


Figure 8.2.4.4. ***Nephrops*** **in FU 32: All recordings of haul duration (hours) made by "Vessel X" in 2003 to 2008.**

Shrimp trawl

The number of shrimp trawlers reporting catches of *Nephrops* in the Norwegian logbooks decreased steadily from 2000 to 2010, with only one vessel in both 2009 and

2010 (Figure 8.2.4.5). The number of shrimp trawl hauls decreased accordingly. In 2009 and 2010 we have data from respectively six and 27 trawl hauls.

The lpue time-series (kg/hr) decreased steadily from 2000 to 2006, and thereafter increased in 2007 and 2008 (Figure 8.2.4.6). All annual means are below 1 kg of *Nephrops* per trawled hour. In 2009, good catches in all six trawl hauls in the logbooks gave an lpue index of 3.6 kg/hr (not shown in Figure 8.2.4.6). The 2010 value is uncertain as it is based on only 27 trawl hauls. The 2011 and 2012 indices were based on trawl hauls with shrimp as the target species (see above), and seem to continue the increasing trend starting in 2007 and 2008. The trend in the time-series with a decrease until 2006 and then an increase until 2012 (ignoring 2009 and 2010) agrees well with the relatively high Danish landings in 1999–2006 and the subsequently decreasing landings until present. On the other hand, there is no information on the Norwegian shrimp fishing grounds before 2011, and low catch rates of *Nephrops* in shrimp trawls may also be explained by shrimp trawlers targeting grounds with good shrimp catch rates irrespective of *Nephrops* catches. From 2011 onwards trawl haul positions are given in the logbooks (Figure 8.2.4.7). In 2011 and 2012 the shrimp fishery by vessels ≥15 m took place in the southern part of FU 32 where it overlapped with the demersal fish fishery. Note that demersal and shrimp trawls often are not correctly recorded in the logbooks (Figure 8.2.4.7).

Norwegian logbook data-conclusion

Two new time-series from large mesh bottom trawls (single and twin) and shrimp trawl (35–40 mm mesh size) (single and twin) will be established from 2011 onwards. The electronic logbooks provide information on both type and number of gear. Gear use is not always correctly recorded and must be checked and possibly corrected by considering mesh size. Mesh size is lacking in the 2011 and 2012 logbooks, but information on target species can be used in distinguishing between shrimp and bottom trawls. Information on the use of twin shrimp trawl back in time has been obtained through interviews with shrimp fishers. Corresponding information on twin bottom trawls has not yet been collected. As a large portion of the Norwegian fleet landing *Nephrops* in FU 32 consists of vessels <15 m, especially north of 60°N, the Norwegian logbook data will continue to be limited.

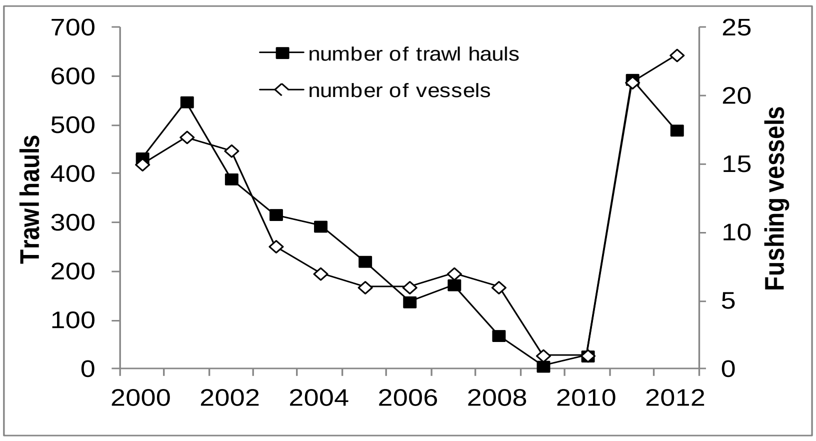


Figure 8.2.4.5. *Nephrops* in FU 32: Number of trawl hauls and number of vessels in Norwegian logbooks for shrimp trawl, per year in 2000–2012. Electronic logbooks were introduced in 2011.

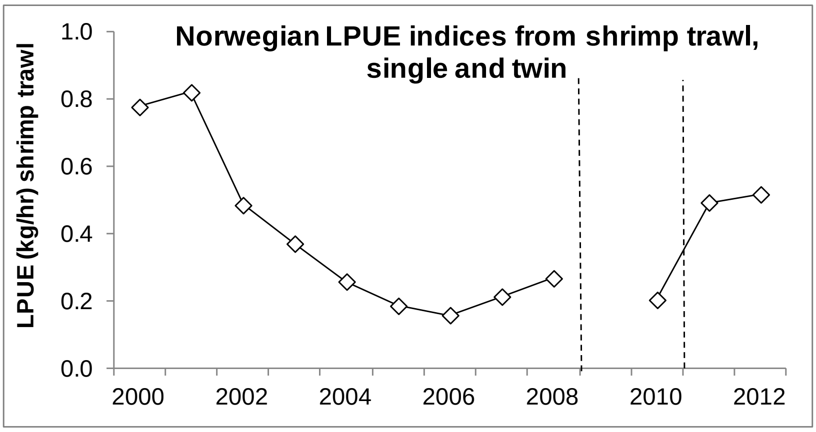
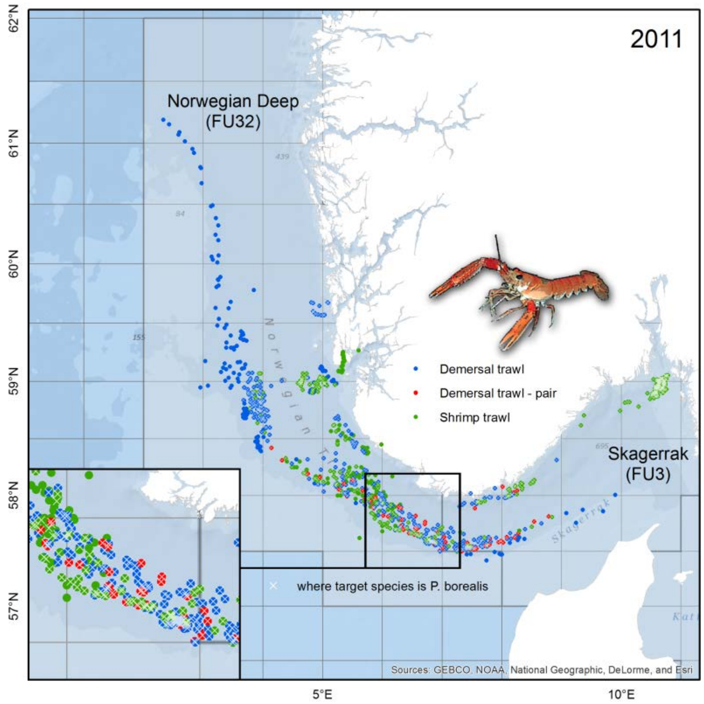


Figure 8.2.4.6. *Nephrops* in FU 32: lpue indices in kg/h for shrimp trawls from Norwegian logbooks, 2000–2012. The dashed vertical lines mark the two years with very limited data (2009–2010) and the two years with electronic logbooks (2011–2012).



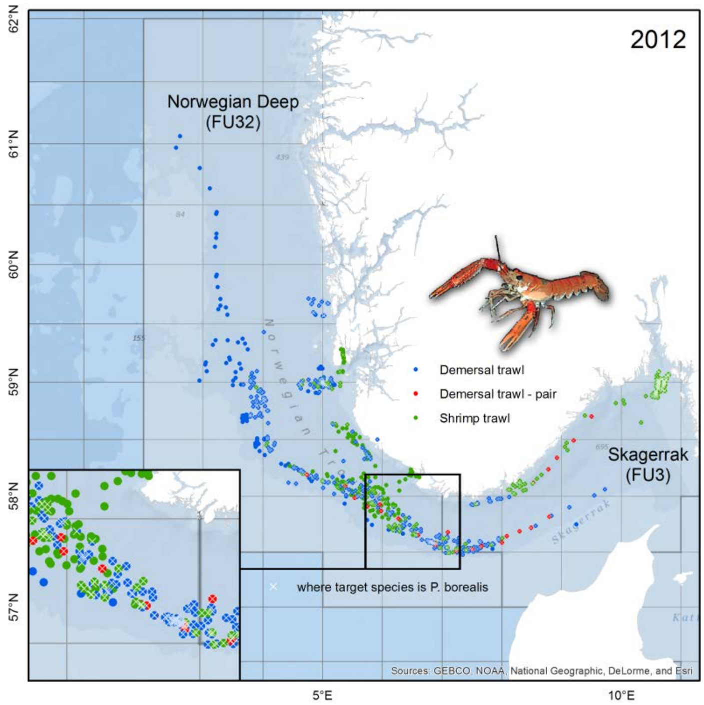


Figure 8.2.4.7. Positions of trawl hauls with *Nephrops* in the catch, per gear from Norwegian electronic logbooks in 2011 (upper figure) and 2012 (lower figure). Enlarged sections illustrate misreporting of trawl gear, where dots marked with a white cross are trawl hauls with target species "shrimp", and dots without a white cross are hauls with target species "*Nephrops*" or a fish species.

Danish VMS data

VMS data show that the Danish vessels fish exclusively in the western part of FU 32 (Figure 8.2.4.8). WK*NEPH* recommends that the Danish VMS data should be presented on an annual basis to illustrate the changing spatial distribution of the Danish fishery. A closer analysis of the VMS data might also provide a detailed picture of the fishable *Nephrops* grounds in the western part of the Norwegian Deep.

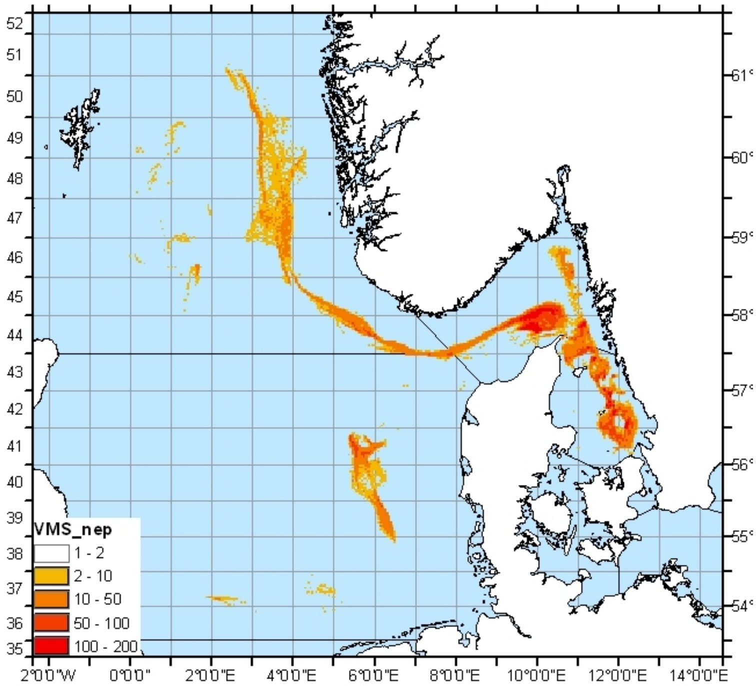


Figure 8.2.4.8. Pooled VMS data showing the spatial distribution of the Danish and Swedish fleet fishing for *Nephrops* in Skagerrak (FU 3), Kattegat (FU 4), and the North Sea. The Swedish vessels are mainly fishing in Kattegat and the northeastern part of Skagerrak.

Norwegian trap fishery

The Norwegian trap fishery for *Nephrops* in FU 32 is increasing (Figure 8.2.4.9). Landings from traps increased from 13 tons in 2001 to 50 tons in 2012, and in 2011 and 2012 trap landings made up respectively 58 and 67% of the total Norwegian landings. Unfortunately no logbook data exist from this trap fishery.

The Norwegian recreational trap fishery for *Nephrops* is also increasing. IMR initiated investigations of this recreational fishery in 2012, with recreational fishers sending in logbooks from all catches, providing monthly data on catch rates, sex ratio, proportion of berried females, and proportion of undersized *Nephrops*. In 2012 four fishermen from FU 32 participated in the study (Figure 8.2.4.10); this number increased to six in 2013. In 2013 the fishermen will also provide length data. Assuming that the recreational and commercial fishery takes place on more or less the same grounds, this study will provide data relevant also for the commercial trap fishery. Investigations of the recreational fishery are also important as a large part of the trap fishery is carried out by non-professionals, with an unknown share of the total removal of *Nephrops*.

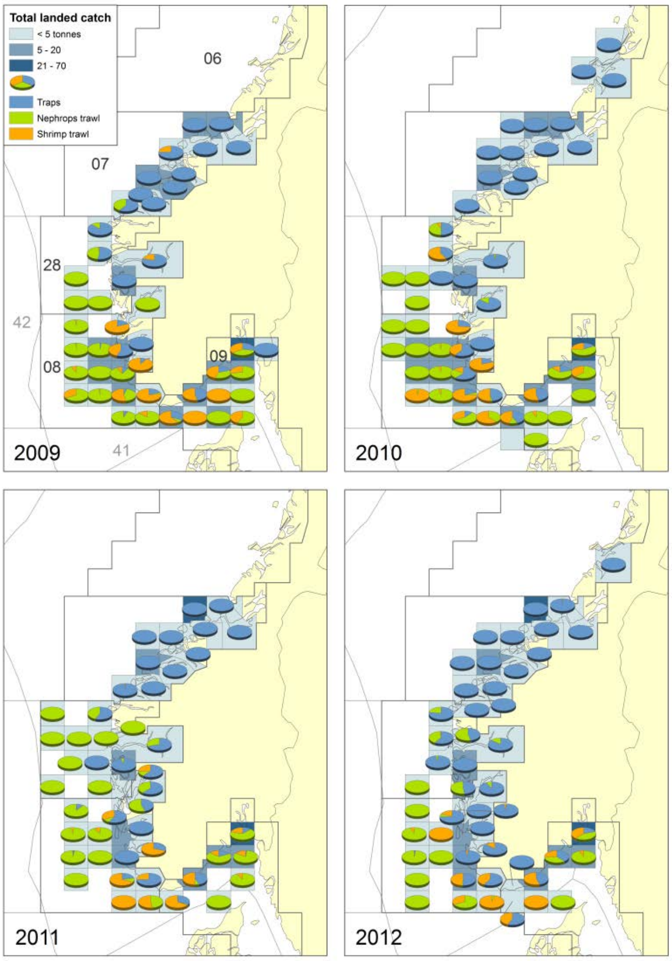


Figure 8.2.4.9. Norwegian landings per ICES rectangle and gear in 2009–2012. Landings per ICES rectangle was not available before 2009.

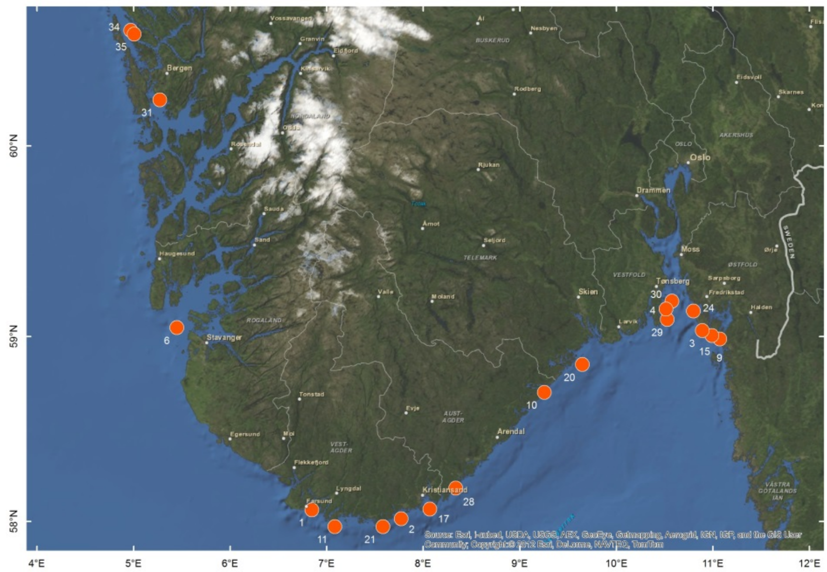


Figure 8.2.4.10. Geographic locations of fishers participating in the 2012 pilot study of the Norwegian recreational *Nephrops* fishery.

8.2.5 Other indicators (Length distributions and others)

See Section 8.2.1.

8.2.6 Industry/stakeholder data inputs

None.

8.2.7 Environmental data

CTD data (bottom temperature and salinity) exist from the Norwegian shrimp survey back to 2006 (Table 8.2.6.1, Figure 8.2.6.1). Mean salinity has varied between 35.15 and 35.26‰, while mean bottom temperature has been between 6.6 and 7.9°C. The low mean temperature in 2011 was due to formation of cold bottom water during the unusual cold winter in 2009–2010. This was still detectable in 2011. The range of measured temperatures has remained at 6.0–8.5°C throughout the survey time period.

Table 8.2.6.1. Bottom temperature and salinity (mean and SD) in FU 32 in 2006–2012, from the Norwegian annual shrimp survey.

	Temperature (°C)		Salinity (‰)	
	mean	SD	mean	SD
2006	7.40	0.58	35.25	0.02
2007	7.90	0.50	35.20	0.07
2008	7.58	0.35	35.18	0.06
2009	7.43	0.32	35.26	0.04
2010	7.30	0.55	35.16	0.05
2011	6.61	0.47	35.15	0.04
2012	7.84	0.75	35.18	0.03

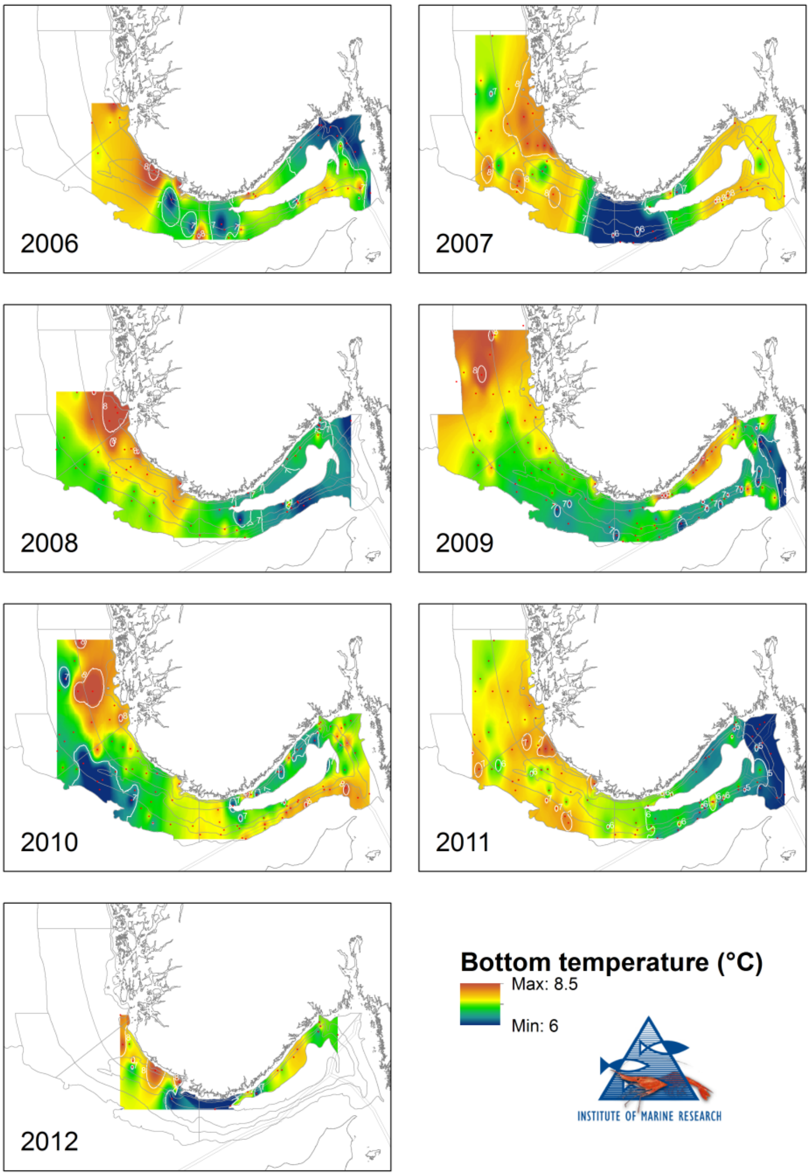


Figure 8.2.6.1. Bottom temperature in January/February 2006–2012 from the Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32).

8.3 Stock identity, distribution and migration issues

See stock annex.

8.4 Influence of the fishery on the stock dynamic

Unknown.

8.5 Influence of environmental drivers on the stock dynamic

Unknown.

8.6 Role of multispecies interactions

Unknown.

8.7 Impacts of the fishery on the ecosystem

Unknown.

8.8 Stock assessment methods

No changes are suggested to the present stock assessment.

8.9 Short-term forecasts, and how the advice is derived

No short-term forecast.

8.10 Biological reference points, reasoning behind choice of recommended exploitation level

None specified.

8.11 Recommendations on the procedure for assessment updates and further work

WK*NEPH* recommends that:

- observer data from the Danish at-sea-sampling programme should be used to obtain information on maturity (males and females), weight-at-length, and seasonal sex ratios. The extra work involved in obtaining maturity and weight-at-length data must be clarified with DTU-Aqua.
- the standard figure with mean lengths in landings and catches should also include mean lengths in discards, and data prior to 2000 should be included in the figure.
- discard data back to 1997 should be made available to the working group.
- data from the Norwegian annual shrimp survey should be explored in more depth with the aim of obtaining a biomass index.
- two new time-series from large mesh demersal trawls and shrimp trawl (35–40 mm mesh size) should be established from 2011 onwards.
- the Danish VMS data should be analysed and presented on an annual basis to illustrate the changing spatial distribution of the Danish fishery, and provide a detailed picture of the fishable *Nephrops* grounds in the western part of FU 32.

8.12 Implications for management (plans)

No management plan is specified.

8.13 References

ICES. 2012 Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) 27 April–3 May 2012, Copenhagen, Denmark. ICES CM 2012/ACOM: 13. 1385 pp.

9 FU 3-4

This FU was initially scheduled for a benchmark at WK*NEPH*2013, but was withdrawn because extensive revisions, triggered by an EU-Norway request, were still in an early phase. The plans for revisions were briefly discussed by WK*NEPH*2013, and some suggestions were provided. The report here just reflects that discussion.

9.1 The EU-Norway request to ICES

The European Union and Norway have agreed that a discard ban on 14 fish species and Northern shrimp should be implemented in the Skagerrak (Division III a N) from 1 January 2014.

It has also been agreed that new technical measures should be implemented from January 1, 2013. These measures will be applicable in the Union's waters of the Skagerrak from 1st of February 2013.

The technical measures to be implemented are:

In the directed *Nephrops* fisheries it shall be mandatory use of sorting grid (35 mm bar spacing) together with a square mesh codend with a minimum mesh size of 70 mm.

In the mixed *Nephrops*/demersal fisheries there will be two options:

1) The basic codend minimum mesh size for these fisheries should be 120 mm diamond mesh or 2) allowing a derogation with the use of a 90 mm codend together with a square mesh panel of 140 mm or a diamond mesh panel of 270 mm in the roof of the trawl (Seltra trawls).
2) The European Union and Norway have agreed that, for those species (stocks) where a discard ban is implemented, all catches (not only landings) should be accounted against the quotas concerned.

In addition to the implementation of a discard ban for the 14 fish species and Northern shrimp, a decrease in the EU minimum landing size for *Nephrops* is envisaged.

ICES is requested to advise on:

1) Estimate the impact of the technical measures in 2013 and discard ban to be implemented in 2014, on the total catch of 14 fish species and northern shrimp in the Skagerrak. Discard rate changes over time should be presented in weight where possible.
2) The proportions of the EU catches of *Nephrops* in the Skagerrak above and below minimum landing size in 2012, and would be expected in 2013, if the above mentioned technical measures are implemented and the EU minimum landing size was i) unchanged or ii) 110 mm or iii) 100, or iv) 85 mm.

9.2 Comments by WK*NEPH*2013

A plan to answer this request was presented at the WK*NEPH* meeting and it was recommended to:

1) Compile selectivity parameters for the newly legislated 70 mm square mesh codends and the different Seltra trawls (90 mm diamond mesh). Then apply the new selectivity properties from the suggested *Nephrops*

trawls on recent *Nephrops* size distributions and estimate the potential discard rate.

2) Estimate the implications of the discard ban of the 14 fish species using the new EU-Norway proposed technical measures and estimate new discard rates for different minimum landing sizes for *Nephrops*.

10 Recommendations

Recommendations are listed under the respective stock sections.

11 References

References are assembled at the end of each stock section.

Annex 1: Terms of Reference

2012/2/ACOM45 A **Benchmark Workshop on *Nephrops* Stocks** (WK*NEPH*), chaired by External Chair Dankert Skagen, Norway and ICES Chair Ewen Bell, UK, and attended by two invited external experts Gerry Scott (USA) and Louise Savard (Canada) will be established and will meet in Lysekil, Sweden 25 February–1 March 2013 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, environmental, multispecies and life-history data.

b) Agree and document the preferred method for evaluating stock status and (where applicable) short-term forecast and update the stock annex as appropriate. Knowledge of environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology;

If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward.

c) Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME results and the introduction to the ICES advice (Section 1.2).

d) Develop recommendations for future improving of the assessment methodology and data collection.

e) As part of the evaluation:

i) Conduct a one day data compilation workshop. Stakeholders shall be invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

ii) Consider further inclusion of environmental drivers, including multi-species interactions, and ecosystem impacts for stock dynamics in the assessments and outlook;

iii) Evaluate the role of stock identity and migration.

Stock	Assessment Lead	WG
Nephrops in Division IIIa (Skagerrak Kattegat, FU 3,4)		WGNSSK
Nephrops in Division IVb (Farn Deeps, FU 6)		WGNSSK
Nephrops in Division VIa (North Minch, FU 11)		WGCSE
Nephrops in Division VIIb,c,j,k (Porcupine Bank, FU 16)		WGCSE
Nephrops in Division IVa (Norwegian Deeps, FU 32)		WGNSSK
Nephrops in Division IVb (Devil's Hole, FU 34)		WGNSSK

The Benchmark Workshop will report by 1 April 2013 for the attention of ACOM.

Annex 2: List of participants

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Annex 3: Brief comment by the invited experts

Comments on the 2013 *Nephrops* Benchmark are offered from the perspective of an overview of the process for development of scientific advice. While there was not adequate time to fully evaluate the data and specific methods applied in the evaluations of each of the numerous stocks considered at the benchmark meeting, a number of comments regarding these are offered below.

In general, the approaches used for providing scientific advice on *Nephrops* stocks (functional units) seem well conceived and appropriately executed, considering the diversity and reliability of different information sources available for the stocks. The approaches adopted are novel in many ways and the *Nephrops* WK should be acknowledged for the creativity involved in its evolution.

Like all forms of stock assessment, these are based on a number of assumptions or estimates that should be verified through additional data collections and studies, to the degree possible. Furthermore, the implications of quantified and/or plausible ranges of uncertainties in components used in developing catch advice should be provided as a way of improving the transparency of the advisory process.

It appears that substantial supplementary information is available for a number of the stocks which should be better incorporated directly into the advisory process. Information on stock response to exploitation could be extracted from time-series that are consistently collected, but are not directly incorporated into the advisory process. While indicators such as shifts in sex ratio or in size of the immature and mature components of the stocks are used as indicators, means of directly incorporating these indictors into the harvest control rule framework of ICES should be further explored. Also, as consistent time-series information sets evolve, application of assessment frameworks that move away from steady state assumptions should be re-evaluated.

Nephrops biology is different from the biology of fish for which many of the concepts and procedures in marine management are rooted. Recognizing this, and the limitations in the data, a creative attitude to developing qualitative or quantitative indicators that can inform on the state of the stock and strain on the stock are encouraged.

A number of specific observations are offered below for consideration for the future:

- The results of UWTV surveys are expressed as density of burrows over the entire area (n/km^2). The generally applied assumption of single occupancy per burrow should be evaluated through experiments designed to test this assumption. It would be also pertinent to test the hypothesis that the occupancy of a burrow could vary with density. There are no biological indicators that can be obtained from the UWTV surveys. Therefore, the complementary use of other types of gears should be explored to allow the collection of samples that could give the population structure of the surveyed stock.
- LFDs could show important variations over the years. The mean length of males and females, the female length-at-maturity and the sex ratio could be considered as good indicators of the reproductive condition of a stock. Therefore, catches should be closely monitored to 1) obtain the catch- and landing-at-length with an adequate precision and 2) obtain biological data by sex relative to the reproductive success of the stock. For example, samples could be collected at a significant time (month or season) relative to

the reproductive schedule. Also, complementary data on the mating success could be collected (e.g. presence of spermatophores).

- Population sampling could be enhanced through, for example, observers on board 'reference fleets', and/or by furthering cooperation/collaboration of industry for dedicated scientific surveys.
- LFDs should be presented in numbers/effort so the strength of cohorts or other demographic features (abundance of large males, recruitment estimates) could be compared between years and used as relative abundance indices.
- Growth rates and natural mortality assumptions for the different stocks are critical to the advisory process adopted and need to be better documented and/or validated through additional study.
- Some stocks show instability in biological parameters like length-at-maturity. Using measures possibly related to biological response to exploitation or strain might be explored to give early warnings.
- Logbook data collection systems appear not to be universally available from the fleet segments harvesting *Nephrops*, although they should be.
- Good usage of VMS data is being made to refine estimates of *Nephrops* habitats for abundance estimation and as these refinements are made, TV survey designs should be reevaluated to make sure they are providing representative samples from the habitat areas.
- The investigation of methods for further incorporating information on population abundance as well as on population productivity should be pursued.

Annex 4: Working documents

Annex 4.1 The Potential for Sperm Competition in *Nephrops* and its effects upon spawning success

Introduction

The sex ratio in commercial landings of *Nephrops norvegicus* typically exhibit an annual cycle with males predominating during the period the females are brooding eggs (the "Berried" stage) as during this time the berried females spend the majority of time within their burrow. The period immediately after egg release can see the females dominate the catches as the male density has been reduced by the fishery in addition to the females having an increased requirement to feed having been largely burrow-bound over the preceding months. A raised proportion of female *Nephrops* in commercial catches at a time where males were expected to dominate the landings have been noted to precede sharp declines in estimates of stock abundance in the Farn Deeps, Porcupine Bank and Iberian Peninsula. One hypothesis suggested for this phenomenon is that the fishery had reduced the abundance of mature males below the level required for successful fertilization at the population scale. Mature females, which would usually be sheltering within their burrows to protect their eggs, would therefore have no need to remain within the burrows and were therefore foraging on the surface and therefore available to trawl gear.

Only as planktonic larvae do *Nephrops* redistribute between mud patches and once recruited to a patch individuals undergo relatively limited movements. It can be envisaged that in situations where male density is reduced to a low level and the search radius of individuals is limited, it is conceivable that females may not encounter males. Farmer (1974) observed mating behaviour in *Nephrops* and found that males searched for females which had recently moulted in order to mate with them. Recently moulted females are very soft shelled and therefore highly vulnerable and appear to remain in their burrows as much as possible, however they are "enticed" out by males for the purposes of copulation.

For a clumped distribution of individuals there will be a range of search areas experienced by the males within the population and the probability of encounter between males and females becomes dependent upon no only the relative densities of the individuals but upon the degree of clustering.

Model description

The encounter rate of male and female *Nephrops* was explored for a variety of sex-ratios and spatial patterns. Population density will, obviously, impact the encounter rate between individuals and to restrict the analyses to plausible densities, data from the annual TV survey of the Farn Deeps stock undertaken by Cefas were analysed to determine typical stock densities. Over the period 2006 to 2010 stock density was determined to be 0.3 per metre squared. The models explored here represent the encounter and mating probabilities over an entire breeding season. It was assumed that in any given year a male *Nephrops* will have 100% probability of encountering and fertilizing an available, mature female whose burrow lies within his search radius.

The fertilization rate where the spatial distribution of individuals is either uniform or uniform-random can be readily determined analytically. Let r be the search radius of a male *Nephrops*, D_m and D_f be the density of males and females respectively.

If the density of males is such that their search radii overlap then the effective search radius of an individual can be approximated to be the midpoint of the mean distance between individuals.

$$r = \frac{0.5}{\sqrt{D_m}}$$

The area searched by each male is simply the equation for the area of a circle and the number of females within this circle therefore becomes

$$N_f = \pi \times r^2 \times D_f$$

Assuming that each male will fertilize all the females within his search radius, the proportion of females fertilized becomes

$$P_f = \frac{N_f \times D_m}{D_f}$$

If males are limited in the number of females with which they can mate in any one season (Limf) then above equation becomes

$$P_f = \frac{\min(N_f, Lim_f) \times D_m}{D_f}$$

If we consider the possibility that females may accept multiple matings then the analytical solution becomes considerably more complex, particularly if we allow the search radius to be non-constant (i.e. related to body size) and it is more practical to use the approach taken for assessing clumped distributions as described below.

Clumped distributions of *Nephrops* were simulated in an individual based model using a Matern procedure to generate the locations of the individuals. For any given realization, the number of clusters (parents) was specified and the coordinates of each parent was selected using a uniform random function. Each individual was allocated a "parent" location using a random poisson process (to generate clusters of different magnitude). From this parental location, the coordinates of the child were randomly generated using a normal distribution with the parent's coordinates defining the mean. The degree of clustering was controlled using the number of parents and the variance around the parent location. Random–uniform distributions can be effectively achieved by specifying a greater number of parents than children. In addition to specifying the number of parents, the dimensions of the simulated space, total number of individuals, maximum number of matings per individual, and proportion of male to female children were input to the program.

For each male *Nephrops*, a search was made to locate females within his search radius. When a male encountered a female a fertilization event took place provided that the maximum number of matings for either male or female were not exceeded.

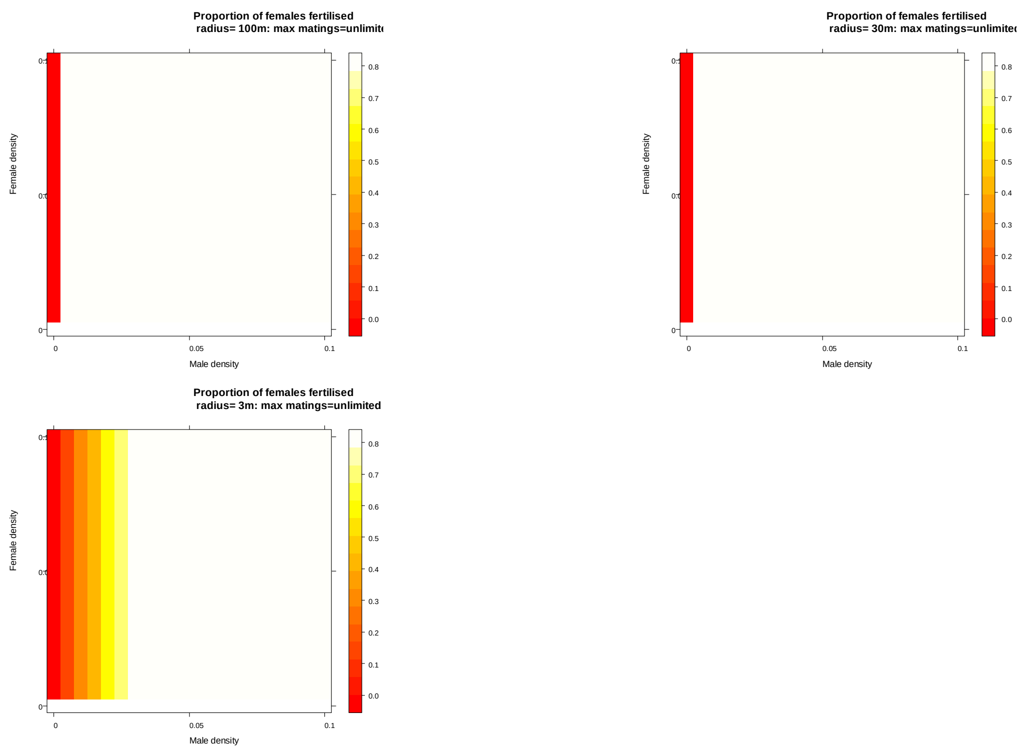
The influence of relative densities of the sexes, number of matings per sex and male search radius were explored. For each combination of input parameters, the proportion of females experiencing at least one mating event was recorded.

In order to simulate spatial patterns similar to those observed in natural populations, the spatial characteristics of natural populations were characterized by fitting semi-variograms to the burrow count data from the Farn Deeps TV survey. Realizations of simulated distributions were then created with the IBM and semi-variograms were determined for these realizations. By varying the parameters for overall stock density, number of parent clusters and the variance around them and then comparing the resulting semi-variograms of the simulated populations with those of the natural populations, it was possible to derive a parameter set which produced similar spatial patterning to the natural stocks.

In the results presented here we have explored the effects of density, sex ratio, search radius and the maximum number of matings each individual can effectively have. 300 simulations of population distribution were created for each set of parameter values and the probability of a female failing to achieve a single mating was determined.

Results

With unlimited mating possibilities and a search radius of 100 m, the only time that females have no mating opportunity is when there are zero males in the population (Figure a4.1). Even when the search radius is reduced to 30 m there is still full mating success across the range of densities. Only when the radius is dropped to 3 m does there start to be any impact of low sex ratio upon the fertilization success when individuals have unlimited capacity to mate. Once the maximum number of matings becomes limiting, then search radii also begin to be more critical. With a 30 m search radius and only three matings, the probability of fertilization drops rapidly with low male density.



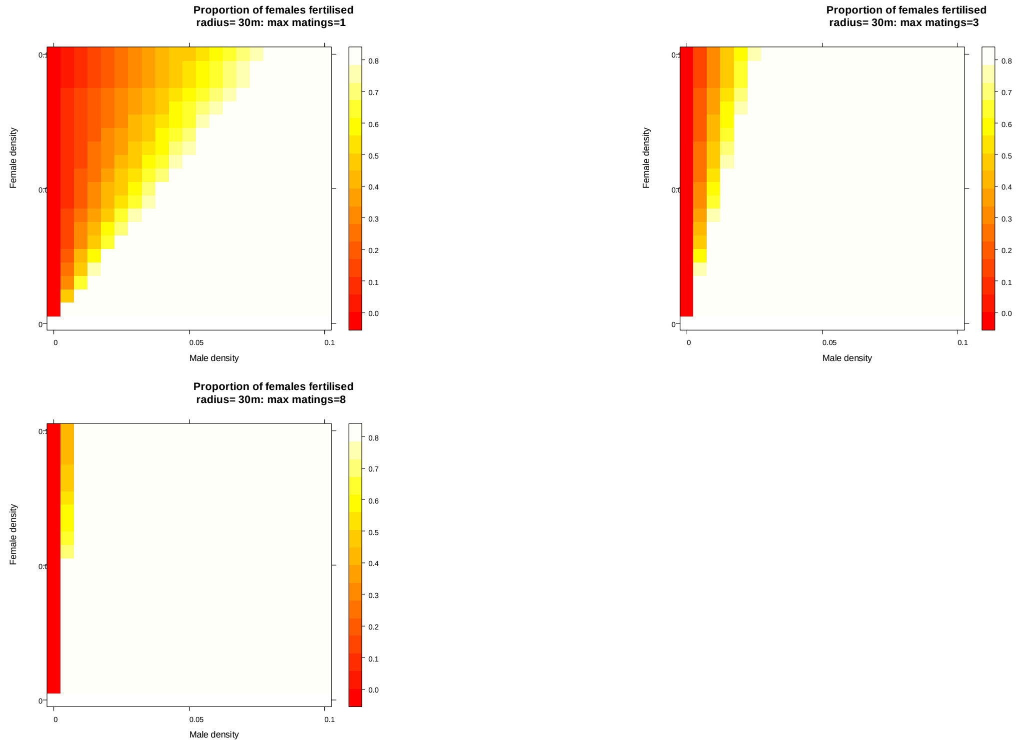


Figure a4.1. Fertilization success probability under a range of search radii, stock density, sex ratio and mating opportunities.

Discussion

The few tagging studies that have taken place with *Nephrops* have indicated that *Nephrops* undergo relatively little movement after the larval phase with a maximum range of around one hundred metres (Chapman and Rice, 1971) between release and recapture points. For a large (20 cm) *Nephrops*, a search radius of 100 m represents 500 body lengths which, when put into a more human context, would represent a search radius of ~1 km. Now for a human to search this radius for potential mates over a year sounds entirely plausible except for the requirement to be able to retreat back to base the moment danger looms. Obviously as the size of *Nephrops* decreases (and a mature *Nephrops* can be ~8 cm), a 100 m search radius is considerably greater. Successfully patrolling an area 500 body lengths in all directions (and surviving) may therefore turn out to be more challenging than would be first expected.

This study only investigated a few factors which may influence mating success and only used spatial patterns similar to those observed on the Farn Deeps. The relative size of available males and females may well be a limiting factor. Farmer (1974) observed successful matings with a size ratio of 2:1 (with the males being larger) which raises the possibility that in instances where the largest males have been removed, larger females may be unable to find a mate physically large enough for fertilization. It is not known if smaller males can effectively mate with larger females, nor how many matings are required to provide enough spermatophores to fully fertilize a clutch of eggs. If there are more factors placing limitations on the ability of females to fully fertilize their eggs, then the probabilities of fertilization success presented here will be an overestimate.

These analyses indicate that provided that sex ratios are not skewed too far and that individuals can manage multiple matings over a reasonable distance from their "home" burrow then sperm limitation should not be an issue, however the possibility does appear to exist. The threshold between full mating success and very low mating success has been demonstrated here to be potential quite narrow. This presents management with two basic options, one is to invest in the determination of the missing biological information (e.g. search radius, multiple mating capacity, size ratio limitations) so as to better understand where a critical threshold might be, and the other is to ensure that fishery practice does not induce significant skews in the sex-ratio of the population. For *Nephrops* stocks, where survivability may not be particularly high, management which involves trying to balance the sex-ratio of the output would not necessarily deliver the desired results. An alternative approach would be to temporally limit the fishery to times when the sex ratio of the landings are more balanced, however this might mean imposing limits on fisheries when they are at their traditional peak.

Annex 4.2 Porcupine Bank (FU 16) Norway lobster (*Nephrops norvegicus*) distribution and biological data; Spanish Porcupine Survey (2001–2012)

González Herraiz, I.; Fariña, C.; Velasco, F., Instituto Español de Oceanografía (IEO), Spain.

Introduction

The Spanish fleet fishes in the Porcupine Bank since 1927 (Paz Andrade, 1958; Anonymous, 2002). In 2009, 137 Spanish vessels operated in the Functional Unit 16, obtaining 8500 tons of hake, megrim, monkfish, Norway lobster and other species (González Herraiz, 2011). 76% of landings came from bottom trawlers and 21% from longliners. Regarding trawlers, there were trips directed to hake, to flat fish and to *Nephrops*, but no vessel was targeting only *Nephrops*. In the trips directed to hake or flat fish, *Nephrops* is a by catch. In 2009, 33 Spanish bottom trawlers (35 m LOA, 456 KW) fished 348 t (around 5 million € in auction) of *Nephrops* in the FU16. The importance of *Nephrops* does not lie in the volume of its landings, but it is a product consolidated in market with high and stable prices (18 €/kg in 2012) (Xunta de Galicia, 2013).

The knowledge of the spatial distribution on the fisheries resources is essential to their study and management. Some studies about the *Nephrops* Irish landings showed differences in length, sex ratio and growth between the western and eastern *Nephrops* populations of the Bank (Hillis, 1988; 1990). There is a *Nephrops* spatial close season in the Porcupine Bank since 2010 (EU, 2010).

The information on the reproductive aspects of the fisheries species population is also crucial in the resources management. Minimum landing sizes and other management technical measures need this kind of information.

Distribution data and data of size-at-maturity according to the spermatophore presence, ovary characteristics and eggs presence from the Spanish Porcupine surveys are presented in this working document.

Material and methods

The Spanish Institute of Oceanography (IEO) performs the Porcupine bottom-trawl survey each autumn/summer since 2001 to assess the demersal resources in the area. This survey is coordinated within the ICES IBTSWG. The survey is carried out on board the research vessel Vizconde de Eza. The gear used is a Porcupine baca; 40/52 with 90 mm mesh size and an inner codend of 20 mm (ICES, 2010). Besides fishing hauls themselves several other data are recorded using CTD Seabird 25, boxcorer, SeaPath 200 system and EK60 echosound. All *Nephrops* individuals caught on the survey were measured and sexed on board. Some individuals were taken to the laboratory, where the presence of spermatophore in thelycum and eggs in the pleopods (ovigerous females) and the ovary maturity stage were recorded. The ovary maturity was classified in five stages, 1 transparent/white and thin ovary, 2 ovary with a salmon colour, 3 soft green ovary, 4 very dark green ovary and 5 salmon and green ovary. If a female was ovigerous or had a maturity stage over 1, it was considered mature. Spatial fishery data were analysed through geostatistics (variograms, kriging) with Surfer software. The L50% of females with spermatophore and mature females were calculated through binary logistic regressions.

Results and discussion

Distribution

The distribution of *Nephrops* abundance per haul allows identifying three distinct patches (western, central and eastern) in the Porcupine area, ranging in depths between 400 and 600 m (Figure 1). Western patch is below 52°N of latitude and around 14°W of longitude, central patch is between 53°N and 52°N and between 13°W–14°W while the eastern patch is over 52°N and under 13°W. Each patch has around 2400 km^2 (± 80 x 30 km).

Analysing the mean sizes by sex and patch for the surveys with more individuals (2010, 2002 and 2001) (Table 1, Figure 2), we can observe that in 2001 and 2002 there is a mean size gradient, the further east, the smaller the individuals are, for both males and females. Nevertheless, in 2010 survey this mean size gradient is not observed, being the mean sizes very similar in the three patches that year.

Table 1.- Number of *Nephrops* individuals caught in each survey.

Survey	Number
2001	1742
2002	1972
2003	781
2004	455
2005	592
2006	420
2007	375
2008	113
2009	760
2010	3073
2011	1087
2012	856

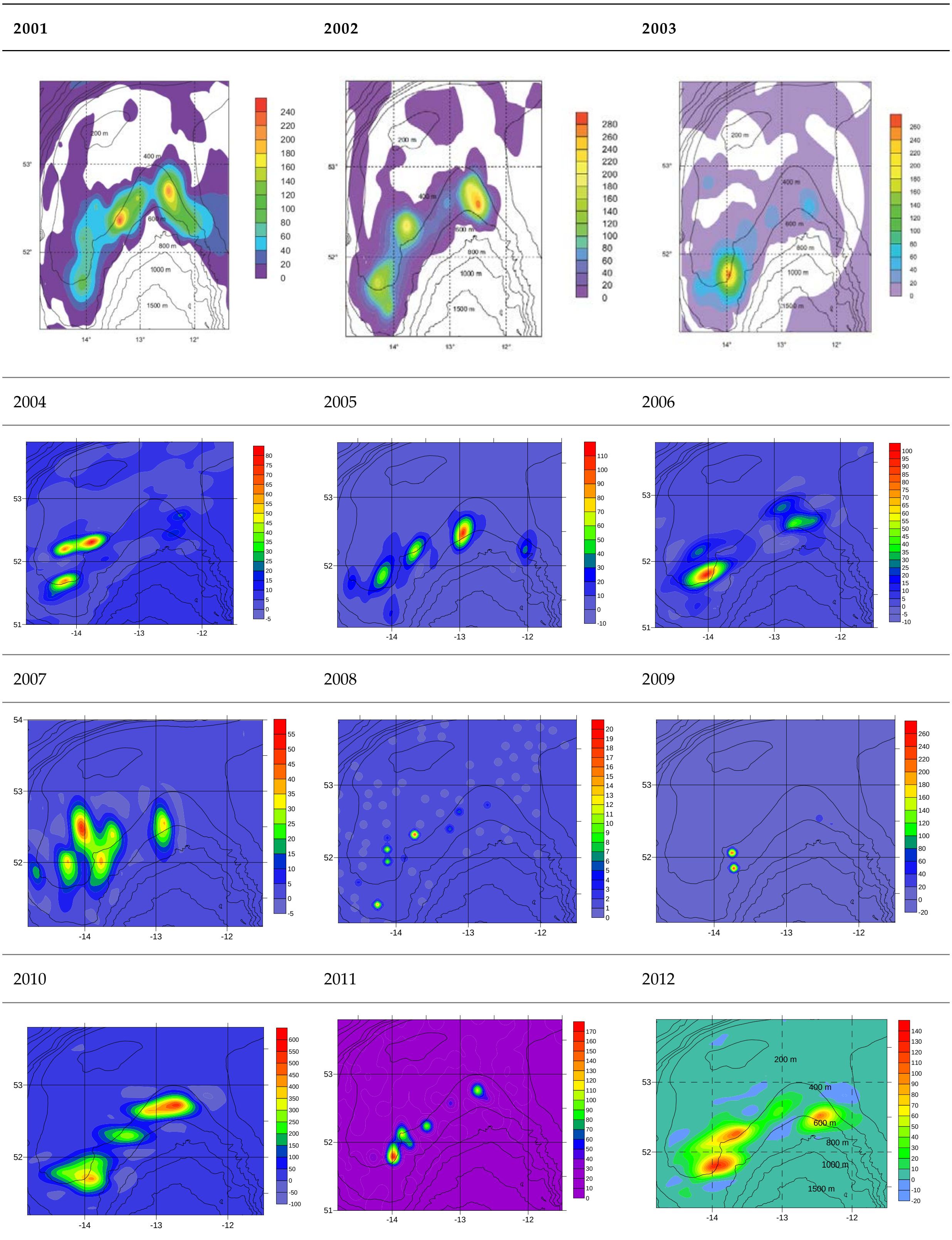
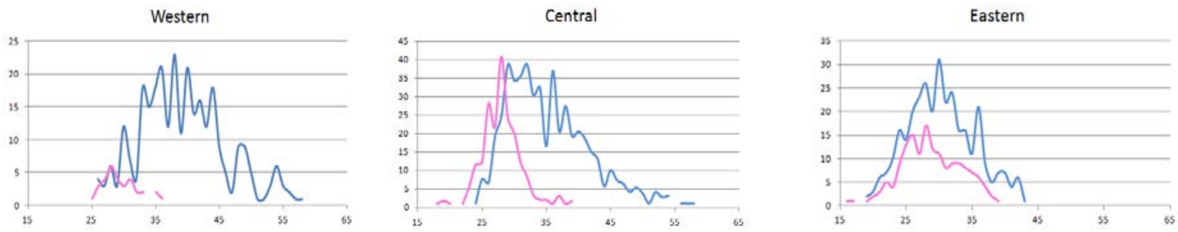


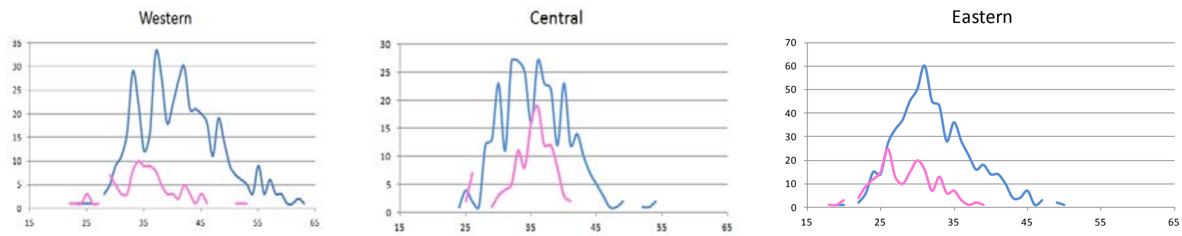
Figure 1. Spatial distribution of *Nephrops* density (number by haul) in the Porcupine Survey (2001–2012).

2001



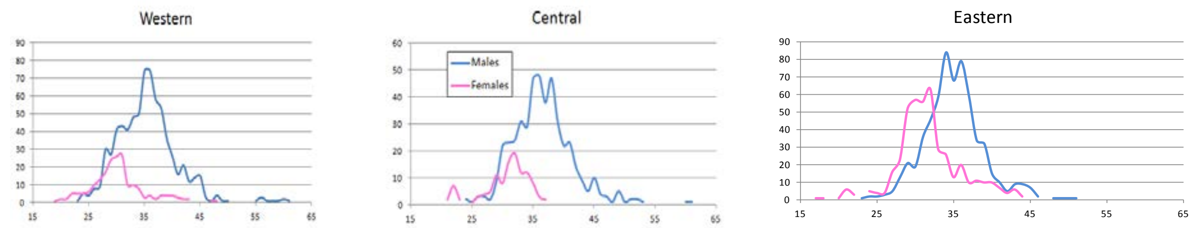
Males: 39.45 mm LC	Males: 35.32 mm LC	Males: 30.39 mm LC
Females: 30.15 mm LC	Females: 28.21 mm LC	Females: 27.89 mm LC

2002



Males: 41.07 mm LC	Males: 35.83 mm LC	Males: 32.35 mm LC
Females: 35.46 mm LC	Females: 31.22 mm LC	Females: 28.51 mm LC

2010



Males: 35.48 mm CL	Males: 36.65 mm CL	Males: 35.07 mm CL
Females: 30.33 mm CL	Females: 31.23 mm CL	Females: 31.85 mm CL

Figure 2. *Nephrops* length distributions (number–length in mm LC) and mean lengths by sex and patch. Porcupine Surveys with higher number of *Nephrops* (2001, 2002 and 2010).

Size-at-maturity

The presence of the spermatophore in the thelycum could be considered one criterion of sexual maturity determination. Table 2 shows the results of the analysis of the spermatophore presence data. The size at which half of the females present spermatophore (50% SP) has high variability of the different samples (i.e. surveys). In some samples all females presented spermatophore, therefore it was not possible to calculate the size at 50% SP (shown as NA in the table). In other cases it was possible to calculate the size at 50% SP, but there were not all spermatophore presence probabilities by length in the sample. Only in four samples (surveys) (2001, 2009, 2011 and

2012) was possible to do both: calculate the size at 50% SP, and have all the different probabilities of spermatophore presence (Figure 3).

Table 2. Size at 50% of females with spermatophore. NA: not available (all females presented spermatophore).

SPERMATOPHORE (SP) PRESENCE IN FEMALES							
Year	Survey		Sample				
	Total number of females	Females mean length (mm CL)	No of females with SP data	Females length range (mm CL)	Females mean length (mm LC)	Size at 50% SP (mm CL)	All % of SP by lenght in sample?
2001	467	28.4	176	15.9–45.6	30.0	24.1	YES
2002	355	31.2	328	16–46.5	30.9	21.1	No
2003	174	31.4	27	14.3–46.5	30.3	NA	No
2004	73	30.0	41	22.5–44.5	32.3	29.0	No
2005	42	33.3	25	23.6–45.2	34.3	26.1	No
2006	33	34.5	25	28.3–45.4	35.0	NA	No
2007	80	37.4	80	28.2–47.3	37.4	26.4	No
2008	39	38.2	37	29.8–46.5	38.8	NA	No
2009	354	28.3	317	10.6–48.3	29.4	38.0	YES
2010	954	31.3	392	17–49	32.9	24.6	No
2011	281	33.5	131	21–51	36.1	27.5	YES
2012	181	30.0	154	18.2–54.4	31.5	36.4	YES

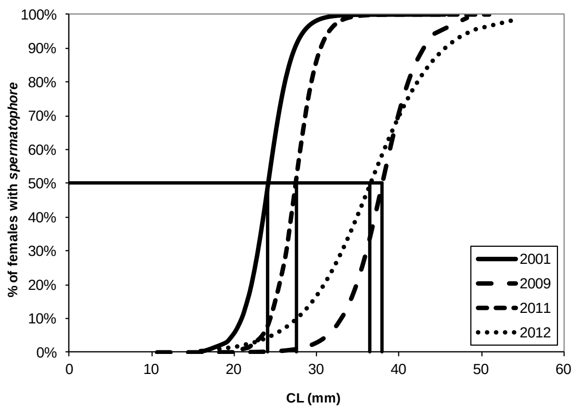


Figure 3. Binary logistic regressions that relate proportion of females with spermatophore and length for each sample. Size at 50% SP: 2001, 24.1 mm CL; 2009, 38.0 mm CL; 2011, 27.5 mm CL; 2012, 36.4 mm CL.

Table 3 shows the results of the females' maturity analyses. The size at which half of the females are mature (50% MA) has a smaller variability between different samples (= surveys) than the size of 50% SP. In some samples all the females are mature; therefore it was not possible to calculate the size at 50% MA (shown as NA in the table). In other cases it was possible to calculate the size at 50% MA, but there were not all probabilities of maturity by length in the sample. In six samples (surveys) (2001–2004, 2009 and 2012) was possible to do both: calculate the size at 50% MA, and have all range of maturity probability by length (Figure 4). A weighted average of size-at-maturity was calculated with the results of these six results, giving a size-at-maturity of 28.7 mm CL.

Table 3. Size at 50% of mature females. NA: not available (all females are matured).

FEMALES MATURITY (MA)							
Year	Survey		Sample				
	Total number of females	Females mean length (mm CL)	No of females with maturity data	Females length range (mm CL)	Females mean length (mm LC)	Size at 50% MA (mm CL)	All % of MA by length in sample?
2001	467	28.4	177	15.9–45.6	30	29.9	YES
2002	355	31.2	322	16–46.5	30.9	27.7	YES
2003	174	31.4	74	16.5–46.5	31.1	28.6	YES
2004	73	30.0	41	22.5–44.5	32.3	31.4	YES
2005	42	33.3	25	23.6–45.2	34.3	28	No
2006	33	34.5	25	28.3–45.4	35	NA	No
2007	80	37.4	80	28.2–47.3	37.4	NA	No
2008	39	38.2	37	29.9–46.5	38.8	NA	No
2009	354	28.3	317	10.6–48.3	29.4	29.4	YES
2010	954	31.3	392	17–49	32.9	24.6	No
2011	281	33.5	130	21–51	36.1	28.1	No
2012	181	30.0	158	6.5–54.4	31.5	27.2	YES
Selection average	1604	29.6	1089	6.5–54.4	30.4	28.7	

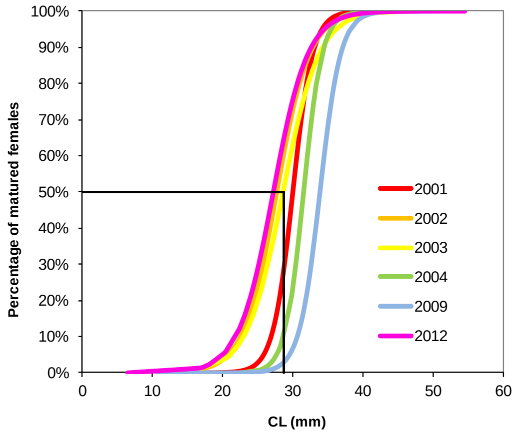


Figure 4. Binary logistic regressions that relate proportion of matured females with length for each sample. Average size-at-maturity: 28.7 mm CL.

Size-at-maturity **by patch** was calculated with the most recent data available (2012) and the results show very low variability (western patch 24.3 mm CL, central patch 26 mm CL and eastern patch 24.6 mm CL). In the case of the central patch not all the range of maturity probabilities by length were found.

The results show variability of the size-at-maturity (higher when the spermatophore presence criterion is used). This variability could be the related with the own variability of a survey based sampling process or with environmental or population aspects. Further analyses must be carried out to clarify these questions.

Acknowledgements

To Begoña Castro Löehmann and Francisco Baldó from the A Coruña and Cádiz Oceanographic Centers (IEO), respectively, and to the people involved in the Porcupine Surveys between 2001 and 2012. Also to our colleagues from the Irish Marine Institute that always are keen to collaborate.

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Annex 4.3 West of Scotland sea loch sediment area

Working Document for the Benchmark on *Nephrops* Stocks in FU 11 (North Minch), Lysekil, Sweden, 25 February–1 March 2013.

Adrian Weetman, David Tulett and Lynda Blackadder, Marine Scotland Science, Aberdeen, Scotland, UK.

Introduction

Marine Scotland Science (MSS) carries out an annual *Nephrops* underwater TV survey in the North Minch (Functional Unit 11) to determine the abundance of *Nephrops* in this area. The results are used to provide management advice in terms of total allowable catch (TAC) for this functional unit. The estimate of absolute abundance is currently believed to be an underestimate as there are additional, unsurveyed areas of *Nephrops* within the sea lochs along the west coast of Scotland.

Both spatial extent of *Nephrops* habitat and burrow density are required to calculate an absolute abundance. Until now MSS had no indication of either value relating to the west coast Scottish sea lochs.

These inshore areas are particularly difficult to survey compared to the more open water areas of the North Minch. These difficulties include:

- a lack British Biological Survey data on sediment distribution within the lochs;
- fishing effort being conducted mostly by small vessels (<12 m) that are not fitted with Vessel Monitoring System (VMS), and so effort and fishing patterns cannot be calculated;
- these areas are geographically small and often densely fished with creels, both of which create a hazard and limit the survey opportunities at each site if the standard towed sledge was to be used.

This paper sets out the methods in which MSS has tried to overcome the first of these issues relating to sediment distribution, to map the spatial extent of *Nephrops* habitat in the west of Scotland sea lochs and presents the findings for consideration.

Methods

Three surveys aboard MRV Alba-na-Mara were carried out in the winters of 2010, 2011 and 2012 (see Figure 1). It was envisaged that over the period of the project all the fished sea lochs in the North Minch on the west coast of Scotland would be surveyed using video cameras and that all available UWTV survey sediment samples would be utilized to help define the boundaries of the muddy sediment within each loch. Using both these datasets the calculated surface area of the viable *Nephrops* habitat would then be merged to provide a more accurate total muddy area within the functional unit for which to calculate *Nephrops* abundance values.

Identifying the edges between the hard and muddy ground in the sealochs using underwater television (UWTV) systems required a different approach to the standard techniques used on *Nephrops* abundance UWTV surveys. Due to the possibility of entanglement with creels and the fact that hard ground was actively being sought out, the sledge could not be used due to the strong likelihood of damage to the equipment and any fishing gear that the sledge may encounter. Alternatively the MSS dropframe was utilized (see Figure 2). This system was deployed from the stern of the vessel (providing accurate positional data) and suspended approximately 1 m off the seabed, which in theory would avoid contact with large boulders or creel ropes.

Station positions were created on arrival in each loch and after an initial surface survey, which identified areas which were not suitable to be surveyed due to creel densities or fish farms. Sites were then evenly distributed around the loch where possible encompassing the extremities of the loch. The start position of each station was located either over mud (which tended to be further away from the shore) as suggested by the admiralty charts and the ship's acoustic sounder or on hard ground very close to the shore. The decision was influenced by the direction of the wind and tide. Once the camera on the drop frame was in visual contact with the seabed, the vessel either drifted on to or away from the shore depending on these environmental conditions.

Data were collected throughout the TV deployment, both electronically (latitude and longitude, depth, video footage, etc.) and from the scientific compliments' observations, and it was these records that defined the boundary between the harder non-inhabited *Nephrops* grounds and those areas which were suitable for *Nephrops*. The length of each deployment varied and was subject to how soon the boundary could be precisely identified; runs lasted between 10 and 55 minutes. At the end of each deployment a sediment sample was taken. In some cases where the vessel had drifted from the softer sediment on to hard ground, the vessel would have to relocate before managing to obtain a suitable sample. Therefore it cannot be assumed that the position of the sediment samples used in the calculations was taken at the end position of each run. Observations were also recorded by the observers where the dropframe could not be deployed, for example in an area with a very high creel density, which was likely to damage the fishing gear and the camera system. This information supplemented the video and sediment sample data and was incorporated in to the calculations.

Once the data were recorded on to DVD and reviewed, the observations, positional data and ground classification information were stored on databases and in spread sheets for later investigation using GIS software.

In order to generate the sediment boundaries within ARC Map 10 (the GIS software package used by MSS) the sediment and video data were initially treated separately. Each loch was dealt with as a separate entity, with the relevant datapoints and associated comments imported from the spreadsheets produced during the survey (see Figure 3).

A simple point to point polygon was then created for each loch. Occasionally this resulted in sections of the shoreline or islands being captured within the polygon. To avoid this situation and generate a more realistic boundary the latest bathymetric data from SeaZone's TruDepth database was used to provide a contour to link UWTV datapoints together (see Figure 4). The depth of the sediment boundary between UWTV observations was based on the bathymetry data which often varied within lochs; therefore a constant depth was not used. This was consistent with anecdotal information. This process generated 15 polygons in the ten areas surveyed.

The sediment data were then introduced to the GIS plot. This layer contained all the datapoints available from MSS UWTV surveys between 2002 and 2011, where the particle size analysis indicated a value corresponding to *Nephrops* habitat; i.e. particle size greater than 63 um in greater than 90% of the sample (as defined by the Folk classification).

Point to point polygons using only the sediment data were also created, encompassing the most extreme points within a loch (see Figure 5). The two sets of polygons were overlaid and in the majority of cases the sediment polygon fell within the extent of the UWTV polygon. There were two methods of dealing with a sediment point that lay outwith the UWTV polygon. On closer inspection if there was contrasting evidence of hard ground as observed on the video footage in the region of the anomalous sediment point then the sediment data were ignored and it was assumed the was sample unrepresentative of the immediate area. (This occurred with data to the northwest and southeast in Loch Laxford; see Figure 6). However if there was no other data available to support or contradict the sediment point then the UWTV polygon was adjusted to incorporate the extension, although using TruDepth contours was not always possible; e.g. southwest point in Figure 6.

Once the data from the UWTV observations and sediment data were finalized in to loch specific polygons, all the data were transformed from latitude and longitude to the British National Grid projection, from where the surface area was calculated.

Results

A summary of the lochs visited, the number of UWTV deployments completed in the study period and the number of sediment samples gathered from within each loch from all MSS surveys is shown below in Figure 7.

This table also displays the calculated surface area for each loch using straight line polygons from the particle size analysis results, in addition to the results from merging both the UWTV and sediment data. The total surface area of 105 km^2 for all lochs on the west coast of mainland Scotland using the best available data represents approximately 4.2% of the total area of *Nephrops* grounds in the open water of the North Minch, based on that area being 2530 km^2 (a value that may be adjusted in light of recent estimates).

This figure is a conservative estimate of the total area in the sea lochs, as the survey activity was frequently limited due to the large increase of mussel farms in the lochs; large areas of high density creel fishing and the poor weather (e.g. when surveying in Cairn Bhain). In addition some small, known fishing grounds went unsurveyed due to weather and time restrictions (e.g. Badcaul Bay). It should also be noted that the surface areas presented in this paper do not take in to account the bathymetry within the polygons, i.e. the polygons are on a flat plane where the true surface area of each polygon would be greater if the topography within the polygons was considered.

Eddrachillis Bay was also partially surveyed but due to the weather conditions the full extent of the grounds were not established. However, although the bay is targeted by creel vessels, large trawlers also work these grounds and this provides VMS data which is already incorporated in the *Nephrops* North Minch assessment.

Conclusion

The initial results from this work indicate that the muddy habitat within the sea lochs is only a very small proportion of the total *Nephrops* grounds of the North Minch. Despite this, the *Nephrops* fishery in the sea lochs has a large influence on local communities. Further detailed investigation of the sea lochs may increase the surface area presented in this report, however it is thought the increase would be marginal.

Work in 2010 comparing burrow density observations over the same grounds was carried out in the Moray Firth using both the sledge and dropframe and showed similar results. Potentially the dropframe could be used to obtain density estimates in the confirmed spaces of the sea lochs, yet the high cost implication in obtaining these data should be considered. Unless these density estimates from within the sea lochs turned out to be significantly greater than those in the main body of the North Minch, their inclusion will not have much of an influence on the present assessment.

Acknowledgements

The authors of this paper would like to thank the skippers and crew of the MRV Alba-na-Mara for their help in conducting this work.

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ICES. 2012. Report of the Working Group for the Celtic Seas Ecoregion (WGCSE), 9–18 May 2012, Copenhagen, Denmark. ICES CM 2012/ACOM:12. 1715 pp.

Figures

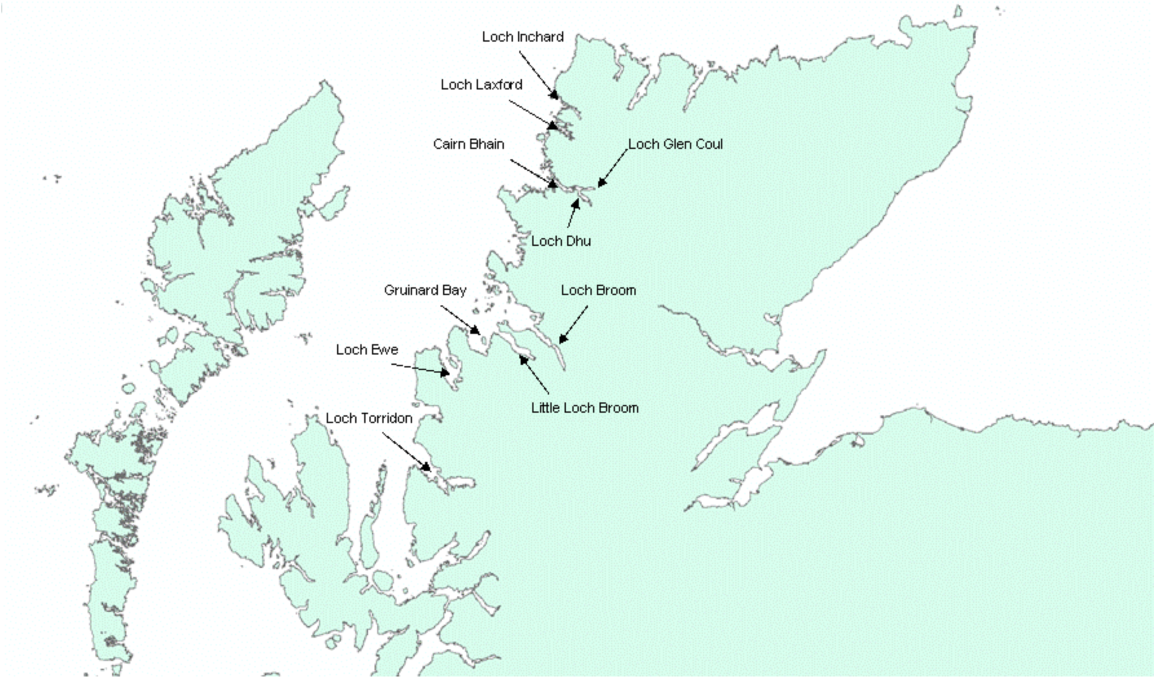

Figure 1. North Minch lochs in which UWTV surveys and sediment samples were obtained for this project.

Figure 2. Image of MSS' suspended drop frame UWTV system used in this survey.

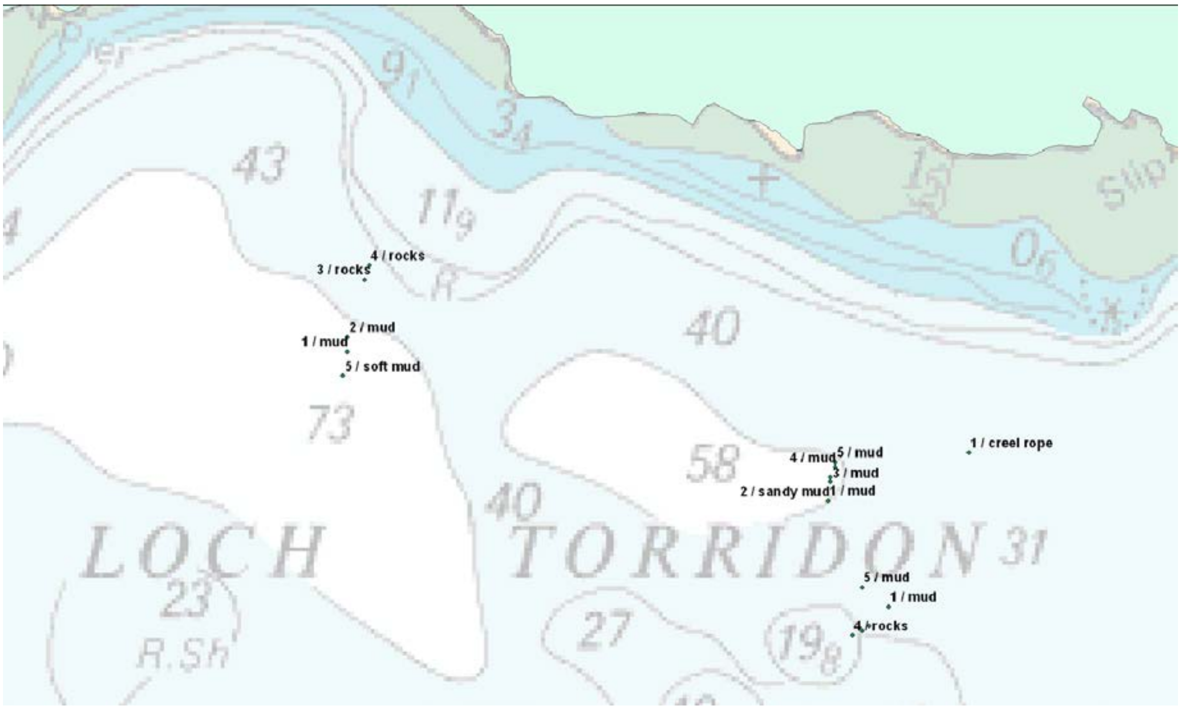

Figure 3. Illustration of recorded comments from UWTV observations in Upper Loch Torridon.

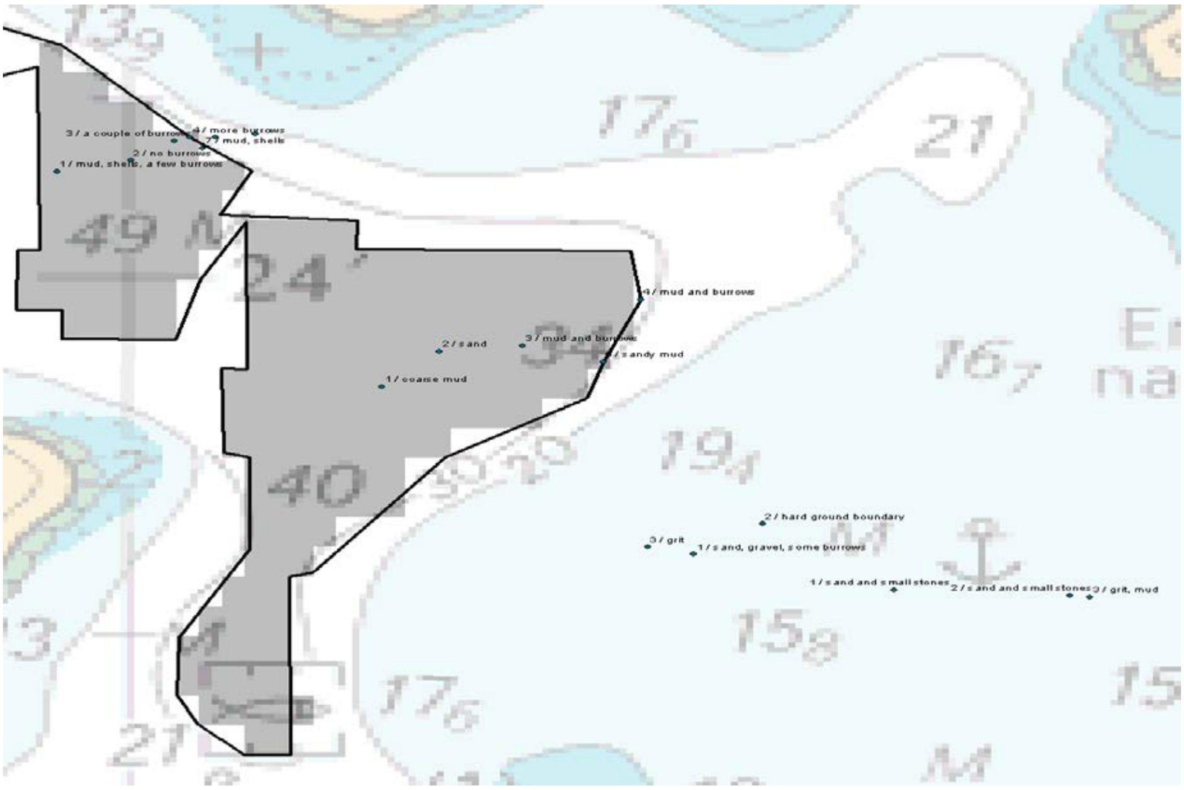

Figure 4. Selection of Loch Laxford with polygon based on UWTV and TruDepeth data.

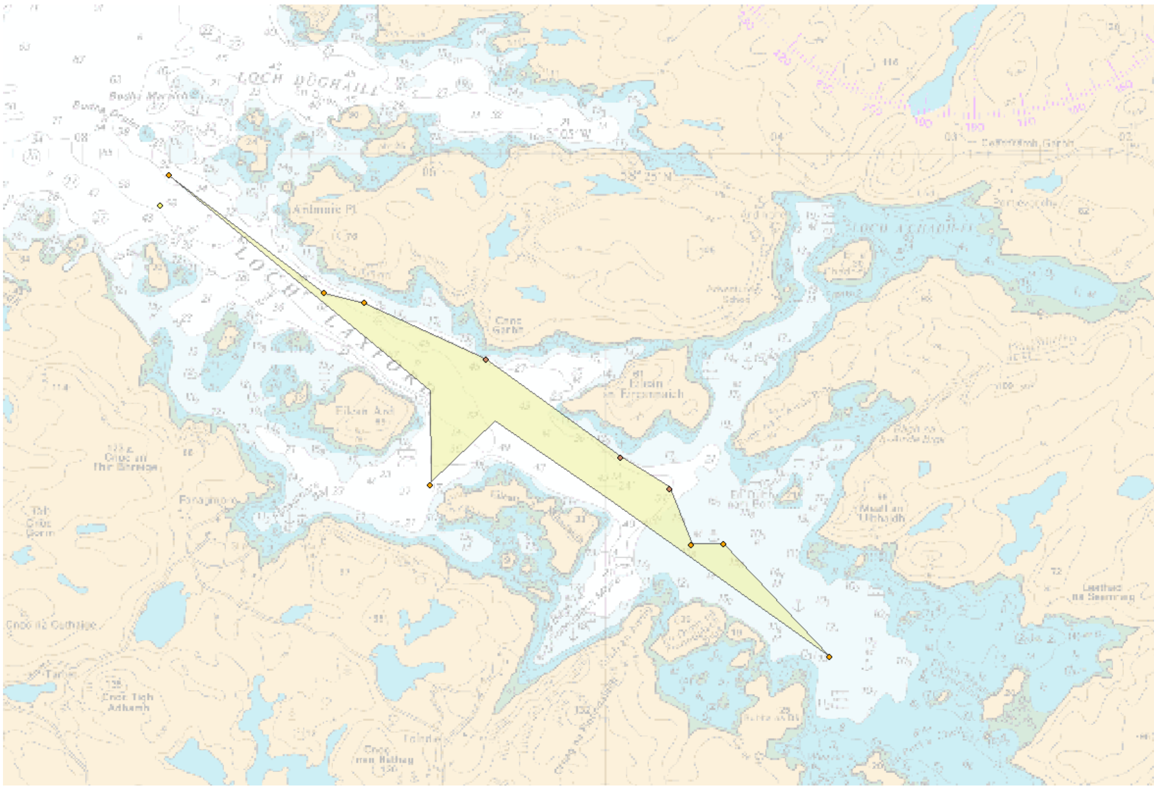

Figure 5. Loch Laxford with a point to point polygon based on sediment sample data where only particles of less than 63 um were found.

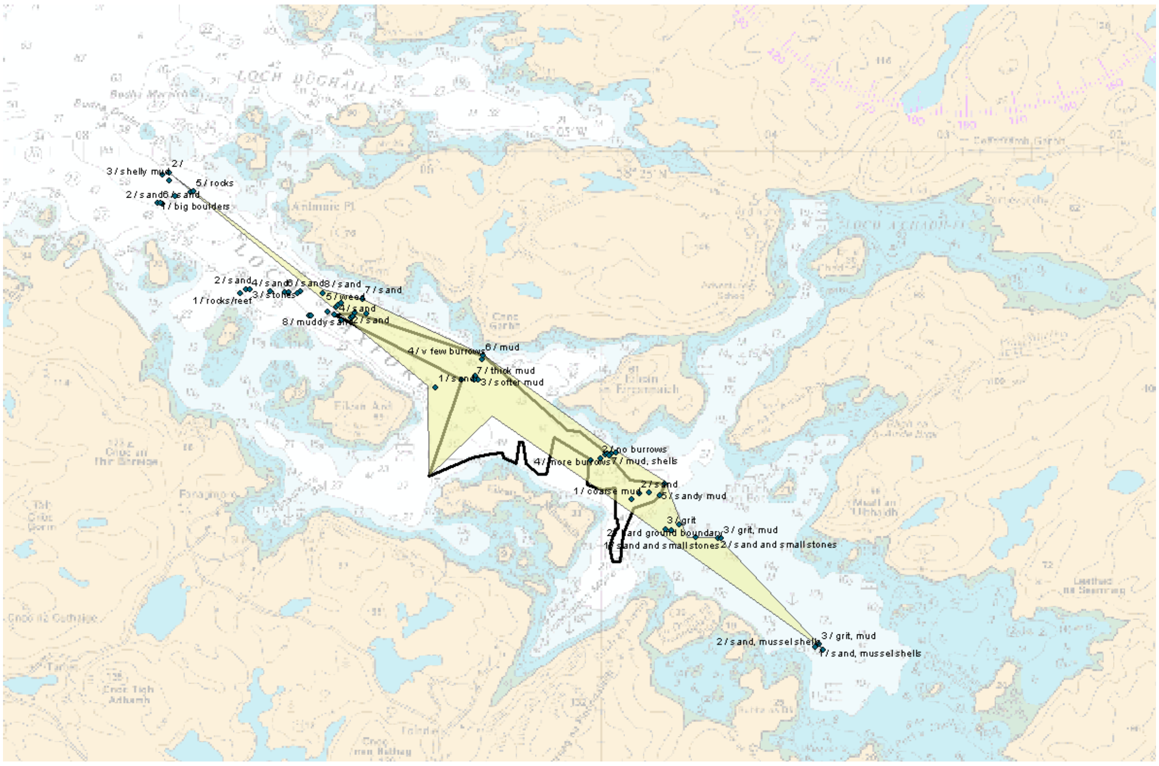

Figure 6. Loch Laxford with the final merged sediment based and UWTV data polygon (black outline).

Table 7. Table illustrating the calculated surface area (km²) of each sea loch using only sediment data and the final, combined, best fit of both sediment data and UWTV observations.

Location	Number of TV stations	Number of sediment samples	Surface area from PSA samples only(km^2)	Surface area all data, best fit(km2)
Loch Inchard	22	20	0.68	1.02
Loch Laxford	11	11	0.75	0.47
Loch Glen Coul	8	8	0.46	1.21
Loch Glen Dhu	6	11	0.38	0.85
Chairn Bhain	6	6	1.66	1.75
Loch Broom	20	23	3.08	6.12
Little Loch Broom	14	15	6.82	11.50
Gruinard Bay	23	25	**NA**	38.64
Loch Ewe	14	11	9.12	9.25
Loch Gairloch	19	22	3.1	8.37
Loch Torridon	31	92	36.62	26.5
Total	**174**	**244**	**62.67**	**105.67**

Annex 4.4 *Nephrops* discard survival in creel fisheries

Working Document for the WK*NEPH*, 25th February–1st March, 2013.

Carlos Mesquita, Marine Scotland Science, Aberdeen.

The creel fishery in the North Minch accounts for around 20% of the total landings and exhibits typically a length composition made of larger animals (ICES, 2012).

In the North Minch creel fishing occurs mainly in the inshore waters and sea lochs while the major component of the trawl fishery catch takes place in the offshore waters, although there is some overlapping between the two fleets.

Discarding of undersized and unwanted animals occurs in the fishery and quarterly discard sampling has been conducted on the Scottish *Nephrops* trawler fleet since 2000, but not for the creel component of the fishery.

The discard rate adjusted for survivorship is required for the adjustment of catches in the assessment and for the provision of catch options. A discard survival rate of 25% has been assumed by the ICES assessment working groups based on studies of *Nephrops* after escape and discard from trawl fishing gears (Charuau *et al.*, 1982; Sangster *et al.*, 1997; Wileman *et al.*, 1999). There are no discard estimates from the creel component of the fishery and therefore it has been assumed that the survival rate is 100%. This working document discusses some of the potential problems associated with this assumption and explores some studies carried out on *Nephrops* discard survival.

Studies on survival of *Nephrops* from creel fishing have been limited to using them as control groups to estimate the mortality of trawl-caught individuals. Wileman *et al.* (1999) reported that during an experiment in the Gairloch area in the North Minch, only three out of 576 controls died in captivity. Harris and Ulmestrand (2004) estimated a survival of 100% of *Nephrops* caught in baited creels off the Skagerrak, West Sweden, used as controls and maintained in holding tanks for over two weeks. Chapman (1981) estimated the survival at 97% after individuals caught in creels were transferred to cages on the seabed in the West coast of Scotland. More recently, Mehault *et al.* (2011) estimated a survival of 88–94% for creel *Nephrops* after re-immersion at the Bay of Biscay. A similar experiment (Campos *et al.*, 2010) carried out off the south coast of Portugal during summertime showed an 84% survival rate for creel *Nephrops* used as a control group for estimating trawl discard mortality.

Chapman (1981) listed several factors that affect mortality of discarded *Nephrops*, among them, (1) damage during fishing and landing, (2) changes in temperature, pressure and light intensity during ascent and descent, (3) exposure to air while in deck and (4) predation by seabirds, fish or other animals during descent.

A large portion of the creel landed *Nephrops* is exported to markets in southern Europe and handling techniques are seen as an important practice that adds value to landings. Adey (2007) describes that discarding *Nephrops* above the minimum landing size is common in loch Torridon and creel fishers perceive that discarded animals will eventually be caught later eventually at a larger and more valuable size. The care in handling discarded *Nephrops* and limited time of exposure to air during creel operation increases their chances of survival. Eye damage due to light exposure had been described in literature (Shelton *et al*., 1985; Gaten, 1988) but according with Chapman (2000), this type of lesion does not seem to influence their long-term survival, growth or reproduction. Predation by seabirds was estimated to be 8.6% of discarded animals in loch Torridon (Adey, 2007) but there seems to be considerable regional variation from area to area, depending on the local populations of seabirds. A similar experiment in loch Fyne (Firth of Clyde) showed little mortality due to seabirds throughout the year. Another factor that differentiates discard mortality in the creel fishery from trawl gears is the fact that animals discarded are returned to the same grounds where they were fished increasing the chances of survival, unlike the more offshore trawl fishery where *Nephrops* may be discarded in unsuitable grounds while boats are steaming.

There is little quantitative information on the levels of *Nephrops* discards from creel fisheries on the west coast of Scotland as observer trips on board of creel boats are not being carried out as part of the MSS sampling programme. Data from creel fished areas such as loch Torridon support that the discard level in the creel fisheries is lower than the trawl fleet which is a reflection of creels higher selectivity for larger animals in the population (Adey, 2007). In addition, most studies on *Nephrops* discard survival make use of creel caught individuals as control groups for the experiments and they have shown very high survival rates. Despite this evidence, some individuals may be discarded because they are damaged while others will be lost to predators. It is acknowledged that although a high survival rate is expected, the true value is unlikely to be 100%. However it is expected that the magnitude of the overall loss associated with the mortality of creel discarded individuals is low and given the absence of data on creel discard rates (data not collected through the sampling programme) the assumption of 100% survival is considered reasonable.

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Annex 4.5 VMS based area definition for North Minch *Nephrops* UWTV Survey

Working Document for the WK*NEPH*, 25th February–1st March, 2013.

Carlos Mesquita, Helen Dobby and Adrian Weetman, Marine Scotland Science, Aberdeen.

Introduction

The North Minch Functional Unit 11 (FU 11) is located at the northern end of the west coast of Scotland (Figure 1). Underwater TV surveys (UWTV) have been used to estimate *Nephrops norvegicus* abundance in Scottish waters for a number of years. In the North Minch, UWTV surveys have been carried out since 1994 (missing surveys in 1995 and 1997). The approach consists of a sledge mounted with TV cameras and towed for a known distance over which *Nephrops* burrows are counted. Assuming a 1:1 burrow occupancy the *Nephrops* abundance in numbers is calculated and raised to the total area. Until 2010, the survey used a stratified random approach based on the sediment distribution (1775 km^2). Owing to its burrowing behaviour, the distribution of *Nephrops* is restricted to areas of mud, sandy mud and muddy sand. The North Minch FU is characterized by numerous islands of varying size and sea lochs occur along the mainland coast and exhibits the patchiest ground amongst west coast FUs. Very soft sediments are found in the southeast while coarser sandy mud prevails to the north and west. Figure 2 shows the distribution of sediment in FU 11.

The sediments distribution around UK is given by the British Geological Survey (BGS, 2002). The accuracy of the currently used boundaries of what is considered *Nephrops* suitable habitat has been considered a source of uncertainty by WK*NEPH* (ICES, 2006; ICES, 2009) particularly in highly heterogeneous grounds such those on the west coast of Scotland where differences between fished area, surveyed area and population area are likely to exist.

Marine Scotland Science recent access to Vessel Monitoring System data (VMS) makes it possible to link geographical information on the positioning of vessels to landings data resulting in more detailed information on the spatial distribution of fishing effort in the *Nephrops* trawl fishery. In 2010, a methodology to calculate areas based on the VMS effort distribution was discussed and area estimates were produced for a number of years in the North Minch (ICES, 2010). At the 2011 meeting of the Working Group for the Celtic Seas Ecoregion (WGCSE) a VMS area (rather than the British Geological Survey sediment area) was used for the first time to raise the UWTV burrow counts and produce an overall abundance estimate. Following the acceptance from the WG, this approach was used again for the 2012 assessment (ICES, 2012).

This report revisits the methods used to calculate the area for the FU 11 UWTV survey and explores further options based on different approaches using VMS data.

Method for VMS area calculation in the North Minch

The VMS positional data were selected from fishing vessels operating *Nephrops* gears (single-rig otter trawl and multi-rig otter trawl, mesh 70–99 mm). In the North Minch the majority of vessels operating those gears land mostly *Nephrops* (Figure 3) with small quantities of fish. To ensure that VMS points used for the area calculation match to those vessels targeting *Nephrops*, trips with at least 75% *Nephrops* by weight were selected.

Geographical positions are available at least every two hours and speeds lower than 4.5 knots were assumed to be associated with fishing. The current satellite monitoring systems are restricted to all fishing vessels over 15 meters in length registered in the UK, which means that smaller trawlers and creel boats fishing for *Nephrops* are not included in this analysis. Five years of VMS data (2007–2011) were used in the analysis.

The method to define polygons around VMS datapoints is based on the alpha convex-hull (Pateiro-López and Rodríguez-Casal, 2010) which is a generalization of the convex hull concept to define and characterize the shape of a set of points. The function depends on a parameter α, which controls the level of detail of each polygon. For a sufficiently large α, the shape of a given polygon is identical with the boundary of the convex hull of the selected points. As alpha decreases, the shape shrinks until that, for a sufficiently small alpha, the shape is an empty set and the area is zero. Different values of α were tested and a value of $\alpha = 0.01$ was chosen over others by visual inspection to represent the spatial features of the polygons in relation to the corresponding VMS points. This method was previously applied to estimate the North Minch VMS area (ICES, 2010).

Different options for calculation the fishing activity area were explored:

- i) Area estimated on an annual basis and averaged over a number of years;
- ii) Area estimated for the entire dataset (all years);
- iii) Area estimated as the intersection of annual polygons;
- iv) Area estimated as the union of annual polygons.

Results

Figures 4–8 show the VMS datapoints and the estimated polygons on an annual basis. Table 1 shows the area estimates over the same period. The extent of fishing activity varies from year to year and appears to be contracting between 2007 and 2011, from approximately 2500 to 2100 km^2.

By inferring polygons from the entire dataset, the area estimate increases to around 3200 km^2 (Figure 9) due to the potential inclusion of low intensity *Nephrops* fishing areas. The intersection of areas corresponding to annual polygons calculated individually for each year (Figure 10) results in a smaller area (1800 km^2) which includes the regions of higher fishing activity common to all years. Another option is to consider the area corresponding to the union of annual polygons (Figure 11). This results in an area of approximately 2900 km^2 and includes the main fishing areas while it excludes some (but not all) low intensity areas.

Table 1. Areas inferred from VMS data using alpha hull polygons in the North Minch (2007–2011). BGS sediment area is also shown.

YEAR	AREAS (KM^2)				
	VMS area/year	BGS sediment	All years combined	Intersection Polygons	Union Polygons
2007	2513	1775	3230	1792	2908
2008	2368				
2009	2419				
2010	2239				
2011	2067				
	Average= 2321 km^2				

Discussion

The sediment distribution around UK is given by the British Geological Survey and the estimated area for the North Minch is 1775 km^2. This area has been used until 2010 to raise the density estimates of FU 11. The analysis of VMS data for trawlers (length >15 m) fishing for *Nephrops* have clearly shown that fishing effort extends outside the sediment areas considered for FU 11. In the 2008 and 2009 TV surveys, a number of exploratory stations were surveyed on the basis of the newly available VMS data and burrows were identified confirming the presence of *Nephrops* outside the BGS sediment grounds. To account for this, a VMS area estimate (2506 km^2, based on year 2009) was used to generate the sampling stations for the 2010 and 2011 surveys and the burrow densities were raised accordingly in the following WGCSE assessment working groups.

The VMS areas calculated for the last five years (Table 1) show some variation over time. An area corresponding to the *Nephrops* spatial extent in FU 11 must be agreed among the several options provided. The spatial extent of fishing activity is variable and a decrease has been observed since 2007. However, the extent of *Nephrops* habitat is likely to be stable from year to year and as such, taking the average VMS area over the last five years would lead to an underestimate of the area ground. Taking the alpha hull area obtained from the entire dataset would result in the inclusion of lightly fished areas where VMS pings are sparsely distributed, especially at the edges of the effort distribution and this is thought to lead to an overestimation of the area. In a situation where the spatial extent of the effort is variable and year dependent, the union of yearly estimated polygons is preferable and considered to be more realistic as this approach would include the main fishing areas while it excludes some of the low intensity areas. This results in an overall area estimate of 2908 km^2 for the North Minch (Figure 11).

The inclusion of VMS data for vessels smaller than 15 meters which will become available from 2012 onwards will provide a better picture of the effort distribution in some of the inshore locations corresponding to smaller trawl boats, but it is not expected this will have an impact in the overall area estimate for FU 11.

The North Minch is subject to both trawl and creel fishing activities, which are overlapping in most regions. However, in a number of areas there is a mismatch between the two fleets, for example in some of the sea lochs in the west of Scotland mainland. The total surface area calculated from the survey carried out at the sea lochs amounted to 105 km^2 (see Working Document Annex 4.3) which is considered negligible compared with the main survey area. Other areas where only creel boats operate include the southeast coast of Harris and the northwest of Skye (lochs Dunvegan and Snizort). These are generally small inshore patches of *Nephrops* habitat fished by small creels boats for which VMS data are not collected. No area estimates are available for those creel regions but it would require the burrow densities to be significantly higher than the rest of the North Minch for this to have an impact on the overall assessment. Future work should consider the mismatch between the trawl and creel fleets operating in the North Minch and map the fishing areas that are currently not considered by the FU 11 UWTV survey.

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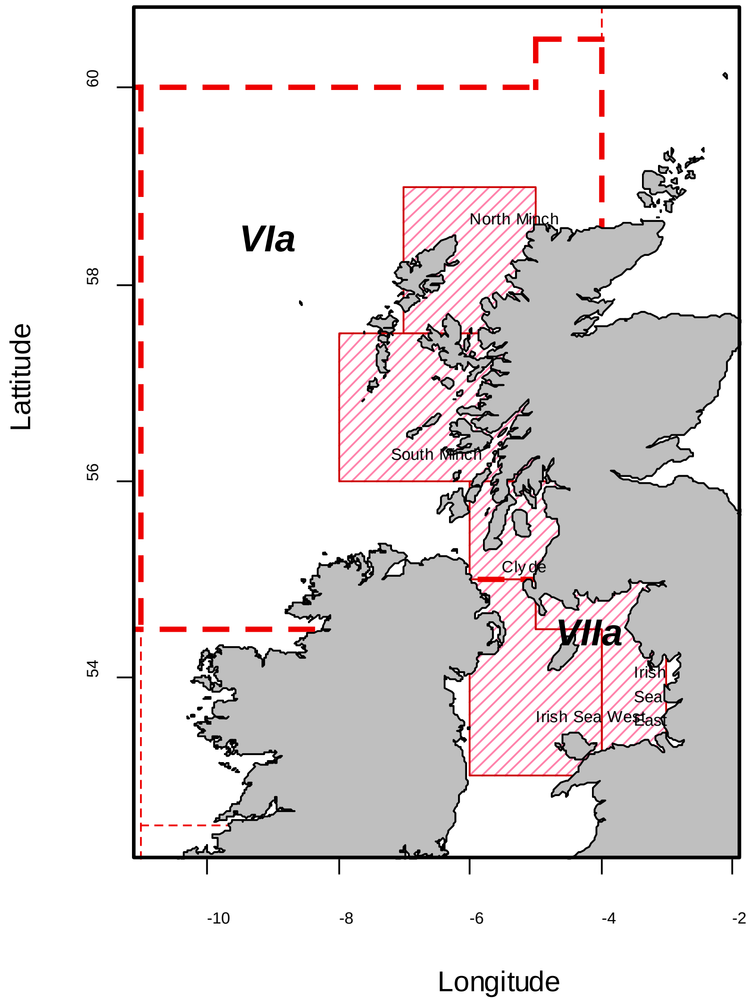

Figure 1. ***Nephrops*** **Functional Units in VIa and VIIa. North Minch (FU11), South Minch (FU12), Clyde (FU13), Irish Sea East (FU14) and Irish Sea West (FU15).**

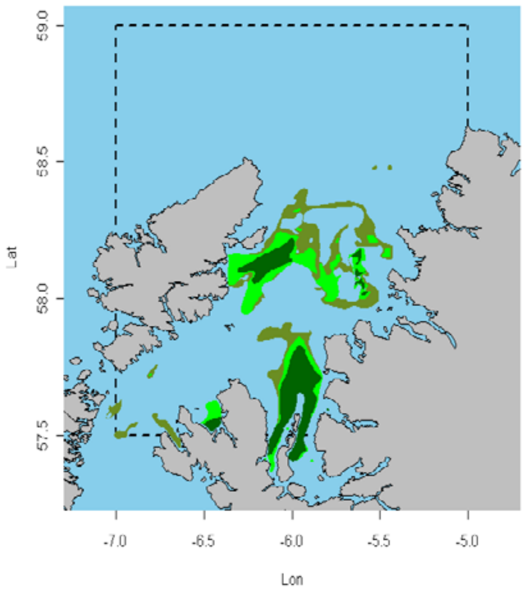

Figure 2. British Geological Survey sediment map for the North Minch functional unit. Sediments are based on the three Folk sediment classification muds: dark green – mud; green – sandy mud; olive drab – muddy sand.

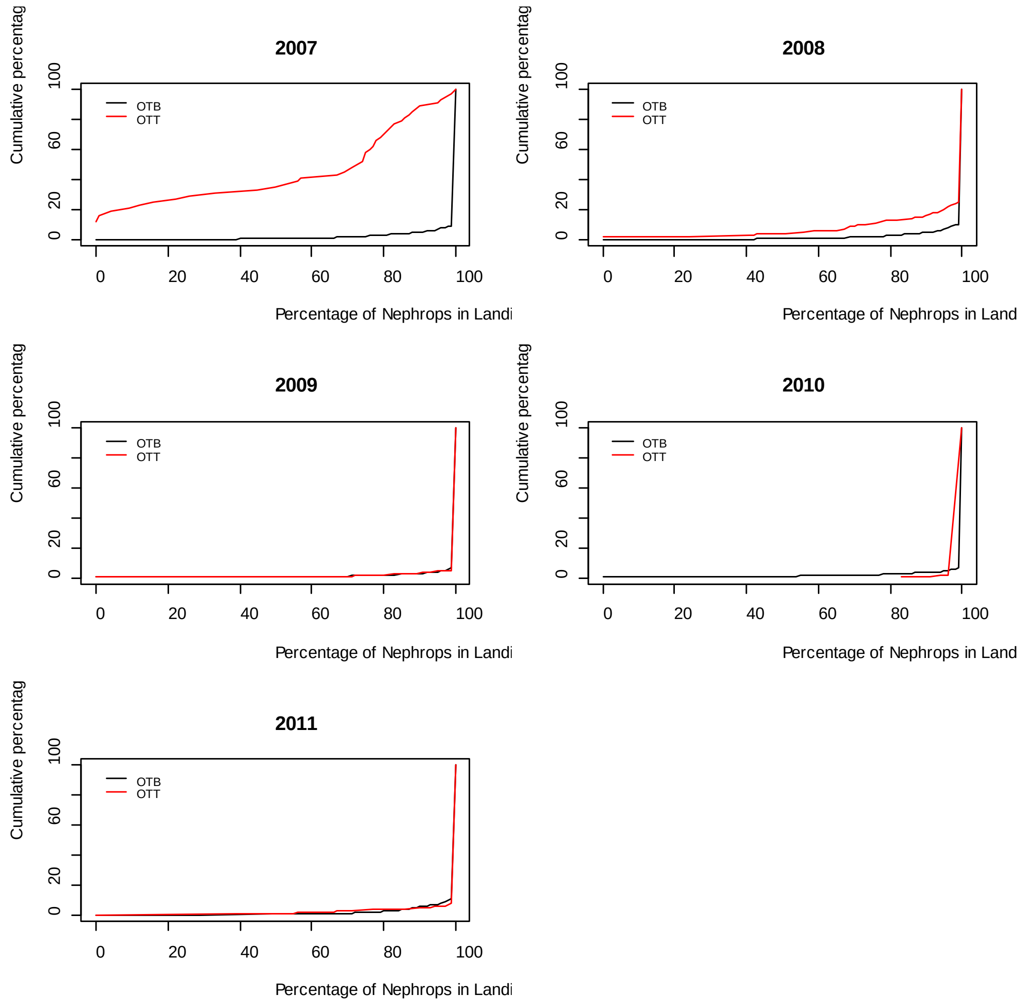

Figure 3. Percentage of *Nephrops* landed per trip vs. cumulative percentage of trips in North Minch, 2007–2011.

North Minch 2007

(a) (b)

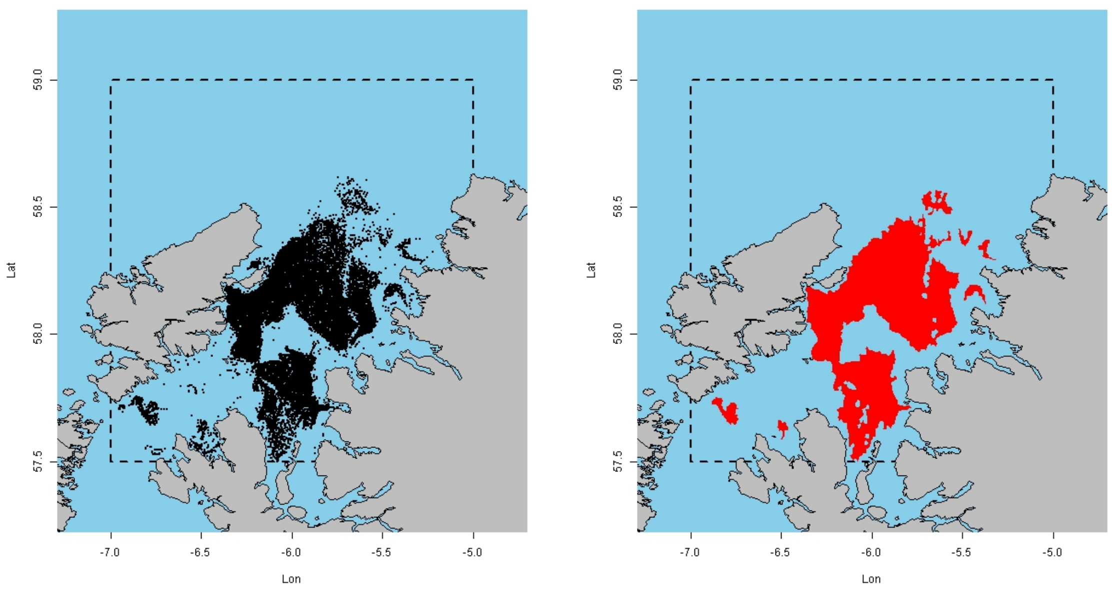

Figure 4. VMS based areas for the North Minch functional unit, year 2007. (a) Distribution of VMS pings recorded from *Nephrops* trawlers (>15 m length). (b) Polygons (adjusted using the alpha convex hull method, alpha = 0.01) used for calculating an area bounding the activity of *Nephrops* trawlers.

North Minch 2008

(a) (b)

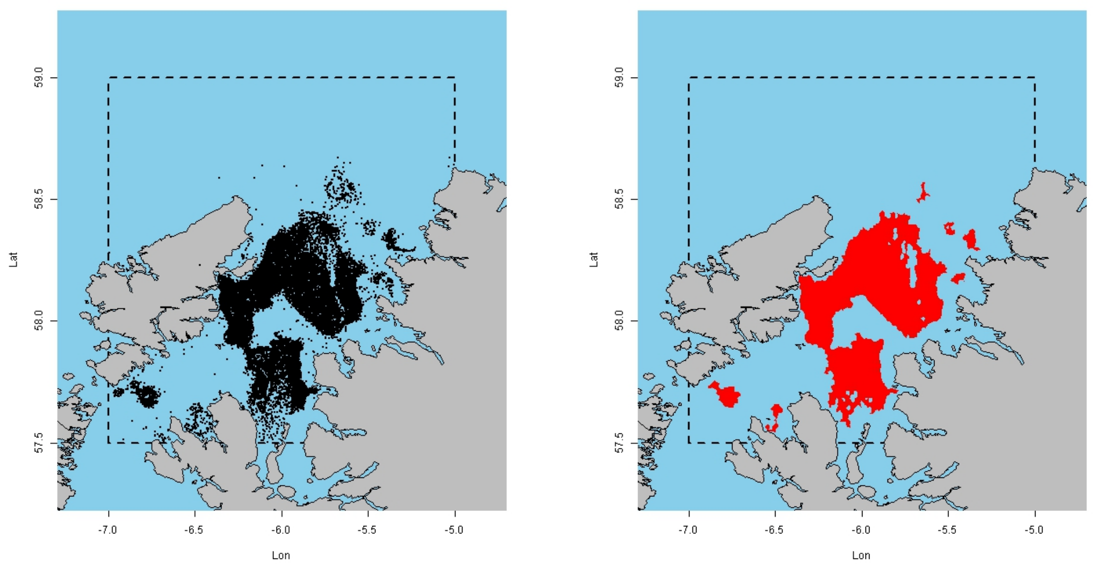

Figure 5. VMS based areas for the North Minch functional unit, year 2008. (a) Distribution of VMS pings recorded from *Nephrops* trawlers (>15 m length). (b) Polygons (adjusted using the alpha convex hull method, alpha = 0.01) used for calculating an area bounding the activity of *Nephrops* trawlers.

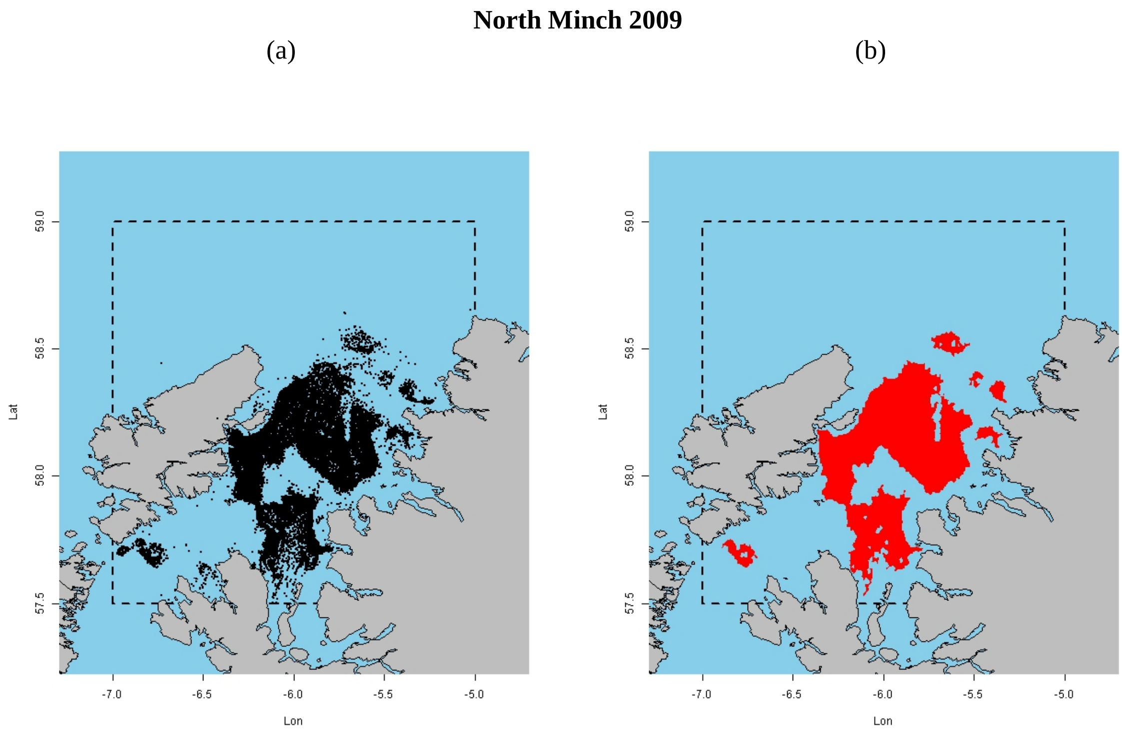

Figure 6. VMS based areas for the North Minch functional unit, year 2009. (a) Distribution of VMS pings recorded from *Nephrops* trawlers (>15 m length). (b) Polygons (adjusted using the alpha convex hull method, alpha = 0.01) used for calculating an area bounding the activity of *Nephrops* trawlers.

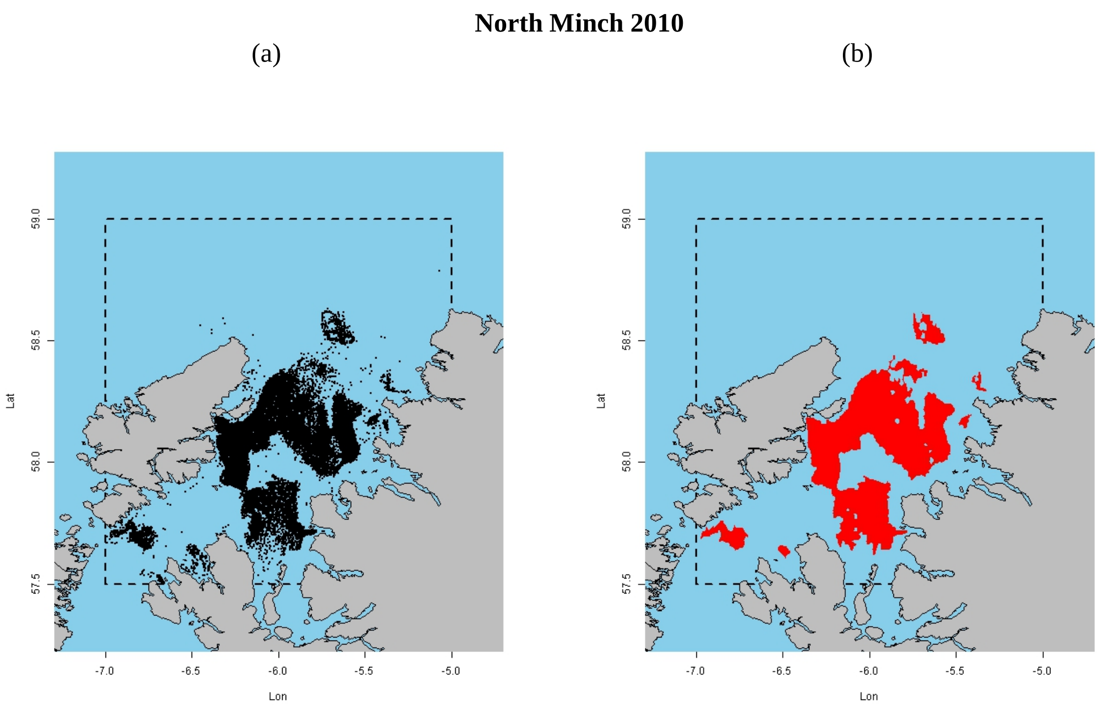

Figure 7. VMS based areas for the North Minch functional unit, year 2010. (a) Distribution of VMS pings recorded from *Nephrops* trawlers (>15 m length). (b) Polygons (adjusted using the alpha convex hull method, alpha = 0.01) used for calculating an area bounding the activity of *Nephrops* trawlers.

North Minch 2011

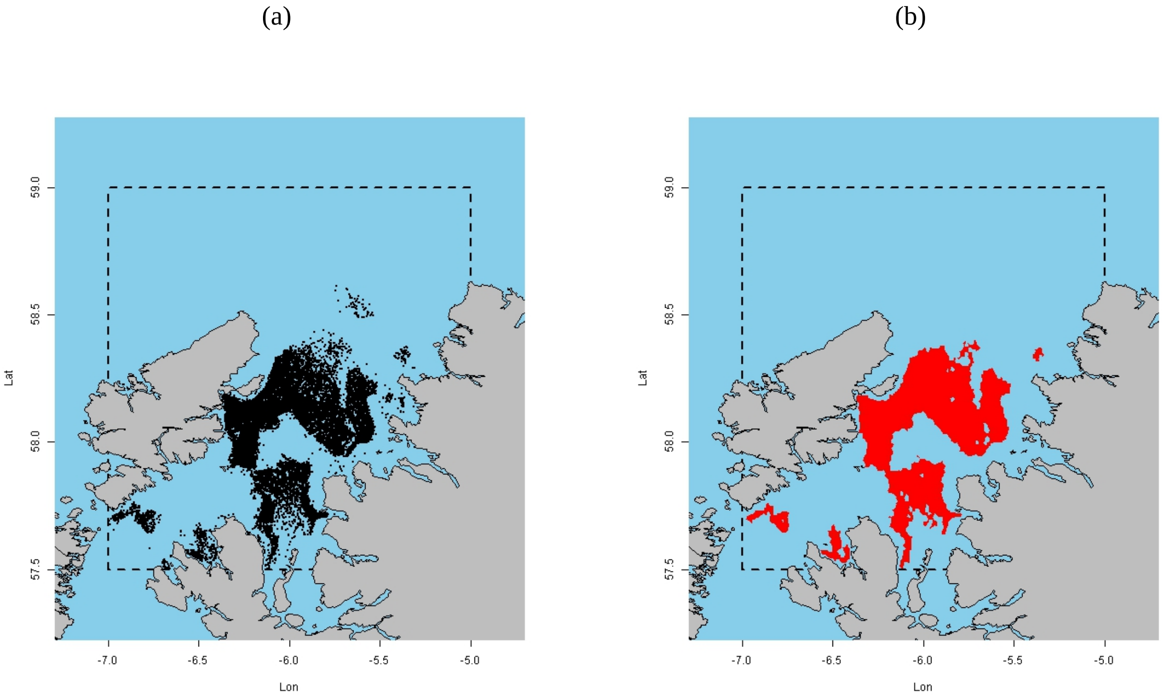

Figure 8. VMS based areas for the North Minch functional unit, year 2011. (a) Distribution of VMS pings recorded from *Nephrops* trawlers (>15 m length). (b) Polygons (adjusted using the alpha convex hull method, alpha = 0.01) used for calculating an area bounding the activity of *Nephrops* trawlers.

North Minch all years combined 2007–2011

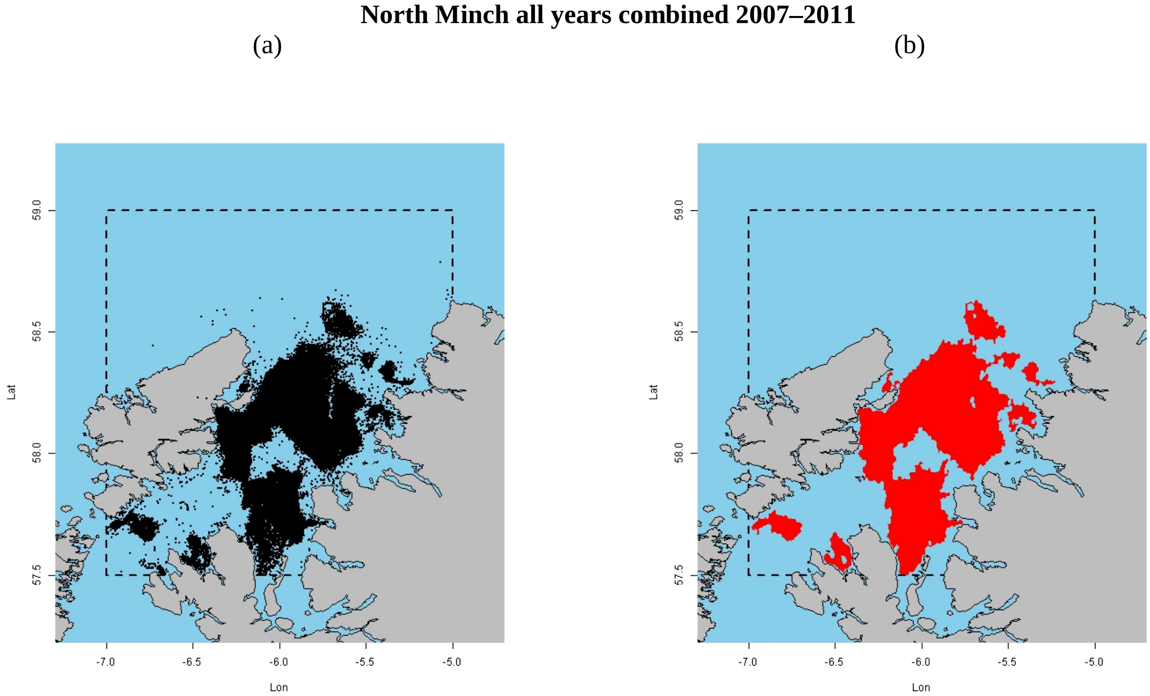

Figure 9. VMS based areas for the North Minch functional unit, using the all VMS points 2007–2011. (a) Distribution of VMS pings. (b) Polygons adjusted.

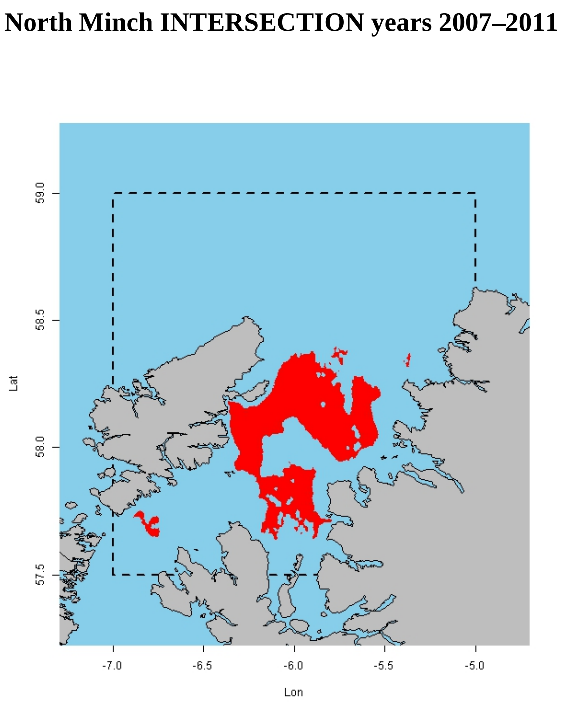

Figure 10. Intersection of annual polygons 2007–2011.

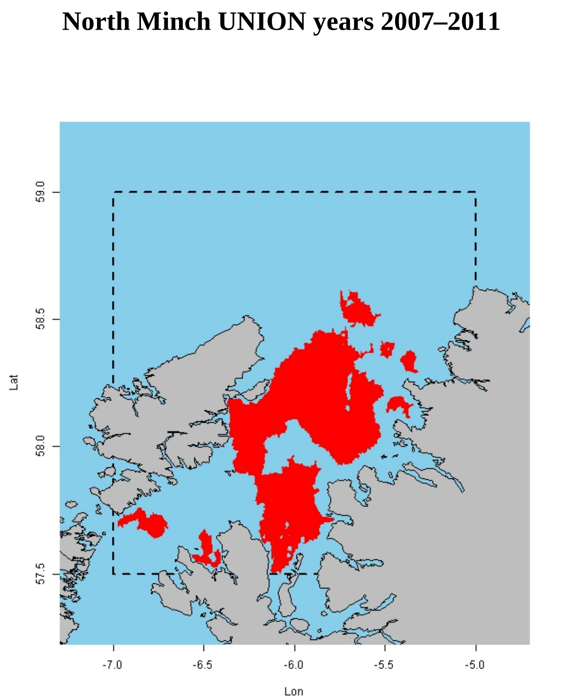

Figure 11. Union of annual polygons 2007–2011.

Annex 4.6 Estimating the frequency of benthic disturbance by *Nephrops* trawling on the Porcupine Bank

Working Document. ICES Benchmark Workshop on *Nephrops* Stocks 25 February–1 March 2013. Lysekil, Sweden.

Hans Gerritsen and Colm Lordan, Marine Institute, Galway, Ireland.

Introduction

Assessing the frequency of trawl disturbance on *Nephrops* grounds is an important aspect of the benchmark process in two regards. First, for all stocks where catch options are directly derived from UWTV abundance estimates an assumption of 100% burrow occupancy is made (ICES, 2009). This is because adult *Nephrops* are known to be very territorial and multiple occupancy of the same burrow system by adult *Nephrops* is regarded as rare (Marrs *et al*., 1996). The general consensus is that unoccupied *Nephrops* burrows are either filled in relatively quickly (i.e. in a few weeks) or will be identified as inactive during the burrow count verification process and not included in density estimates. A number of identifiable cues indicate whether a burrow is active e.g. track marks, recent ejecta and well maintained entrance.

The persistence of unoccupied burrow systems on the seabed is likely to be function of natural disturbance and sedimentation rates as well as man-made disturbance through physical disturbance and sediment resuspension by fishing activity. The deep nature of the Porcupine Bank and relatively low seabed stress might mean that burrow systems persist unoccupied for longer than in many shelf fishing grounds. The estimating the scale and frequency of trawling activity on the Porcupine Bank is therefore important to justify the assumption that burrows have 100% occupancy. The frequency and intensity of trawling has been used in many other *Nephrops* grounds as a justification of this assumption.

The second important reason to quantify the frequency of *Nephrops* trawling impact on the seabed relates to the benthic ecosystem and vulnerable species and habitats. OSPAR have designated sea pens and burrowing megafauna communities as threatened and/or declining habitats in the waters around Ireland (OSPAR, 2010). The sea pen species *Funiculina quadrangularis* is undoubtedly sensitive to trawling and has been observed at low numbers during the 2012 UWTV survey (Lordan, Unpublished data). In a review Power and Lordan (2012) found that the distribution of groundfish survey catches of *F. quadrangularis* did not overlap with the main *Nephrops* fishing grounds suggesting that the distribution of *F. quadrangularis* is not necessarily coincident with *Nephrops*. *Nephrops* trawling has considerable impact on the benthic ecosystem but the process involved are very complex and not that well understood or studied. However, there is an increasing realization that maintaining of key ecosystem services and preserving vulnerable species and habitats is an important aspect of sustainable management of *Nephrops* fisheries into the future. Assessing the frequency of benthic disturbance by *Nephrops* trawling is an important development in this regard.

Methods

The area impacted by fishing gear on the Porcupine *Nephrops* bank was estimated using methods outlined by Gerritsen *et al.* (2013). This approach provides absolute estimates of trawling impact from point data and is not sensitive to an arbitrary choice of grid cell size. The method involves applying a nested grid and estimating the swept-area (area covered by fishing gear) for each VMS point. The ratio of the swept-area to the surface area of a cell can be related to the proportion of the seabed that is impacted by the fishing gear a given number of times. The accuracy of this swept-area ratio method has been validated using known vessel tracks from AIS (Automatic Identification System). In the Porcupine Bank international VMS data from vessels using otter trawls during 2006–2011 was used in the analysis. The width of the trawl that impacts on the seabed was assumed to be 75 m (this was based on the estimated average door spread in the area for Irish *Nephrops* vessels).

Irish logbook data linked to VMS are used to estimate the proportion of *Nephrops* in the landings (based on methods described in Gerritsen and Lordan, 2011). The area of the ground was based on the polygon used to delineate the ground boundary for the UWTV survey conducted in 2012 (Lordan *et al.*, 2012).

Results and discussion

The *Nephrops* grounds are clearly distinguishable (Figure 1) the total area of the ground was estimated to be 7100 km^2. Figure 2 shows the mean number of times each grid cell in the area was impacted by fishing gear. Particularly in the northeastern side of the grounds it is not uncommon for a location to be impacted five times or more per year. Table 1 shows that 44–64% of the area is impacted at least once per year by fishing gear; 8–28% is impacted at least twice; 2–10% at least five times and 0–1% at least ten times per year. Figure 3 shows the proportion of each grid cell that is impacted a given number of times.

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OSPAR. 2010. Background Document for Seapen and Burrowing megafauna communities. OSPAR Commission 2010, London. Publication number: 481/2010.

Table 1. The estimated area that is impacted by fishing gear a given number of times. The total area is estimated to be 7100 km^2. The percentage of the total area is given in brackets.

YEAR	AREA (KM^2) IMPACTED AT LEAST ...			
	Once	Twice	Five times	Ten times
2006	4579 (64%)	1421 (20%)	443 (6%)	42 (1%)
2007	4977 (70%)	1852 (26%)	698 (10%)	71 (1%)
2008	4023 (57%)	1007 (14%)	251 (4%)	14 (0%)
2009	3140 (44%)	561 (8%)	109 (2%)	2 (0%)
2010	3710 (52%)	1039 (15%)	329 (5%)	33 (0%)
2011	4569 (64%)	1967 (28%)	723 (10%)	49 (1%)

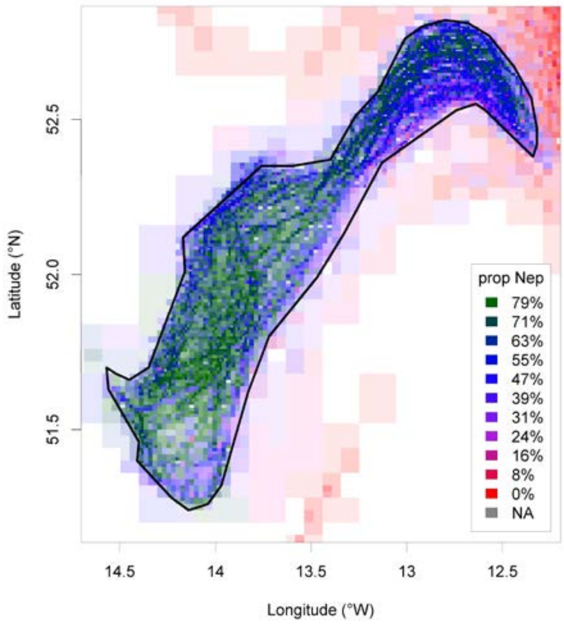

Figure 1.The proportion of *Nephrops* in the Irish landings (indicated by the colours). Dark shades correspond to high levels of international effort. The black line is a polygon that was is used to define the grounds for the UWTV survey.

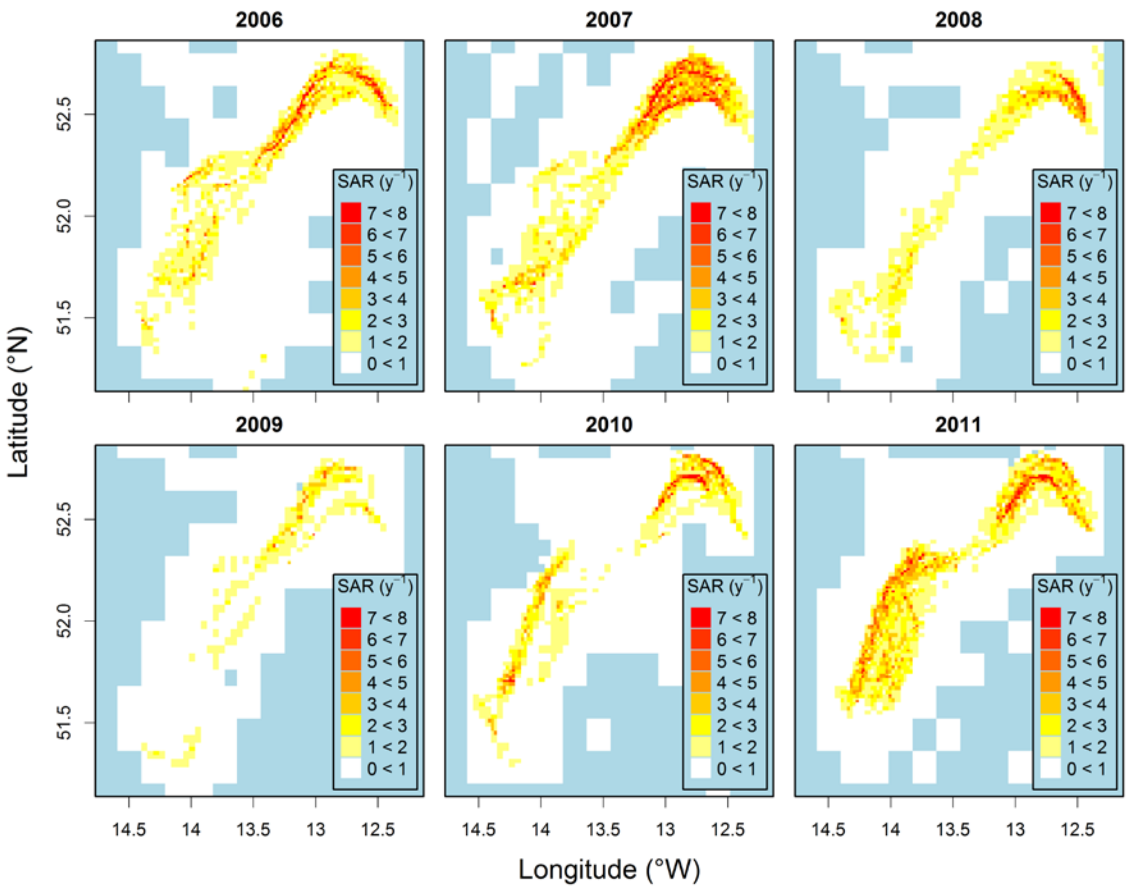

Figure 2. Swept-area ratio (SAR) or the mean number of times each grid cell is impacted by fishing gear for the years 2006–2011.

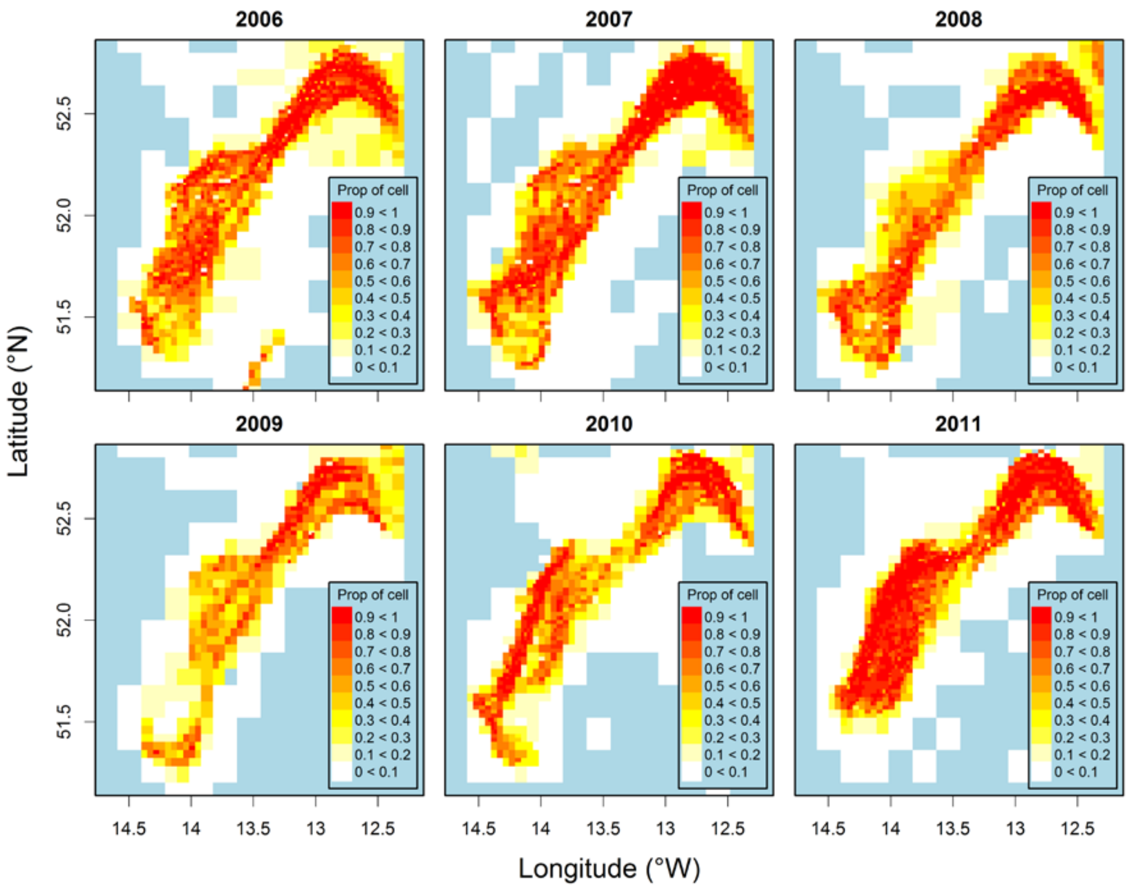

Figure 3a. The proportion of each grid cell that is impacted at least once per year.

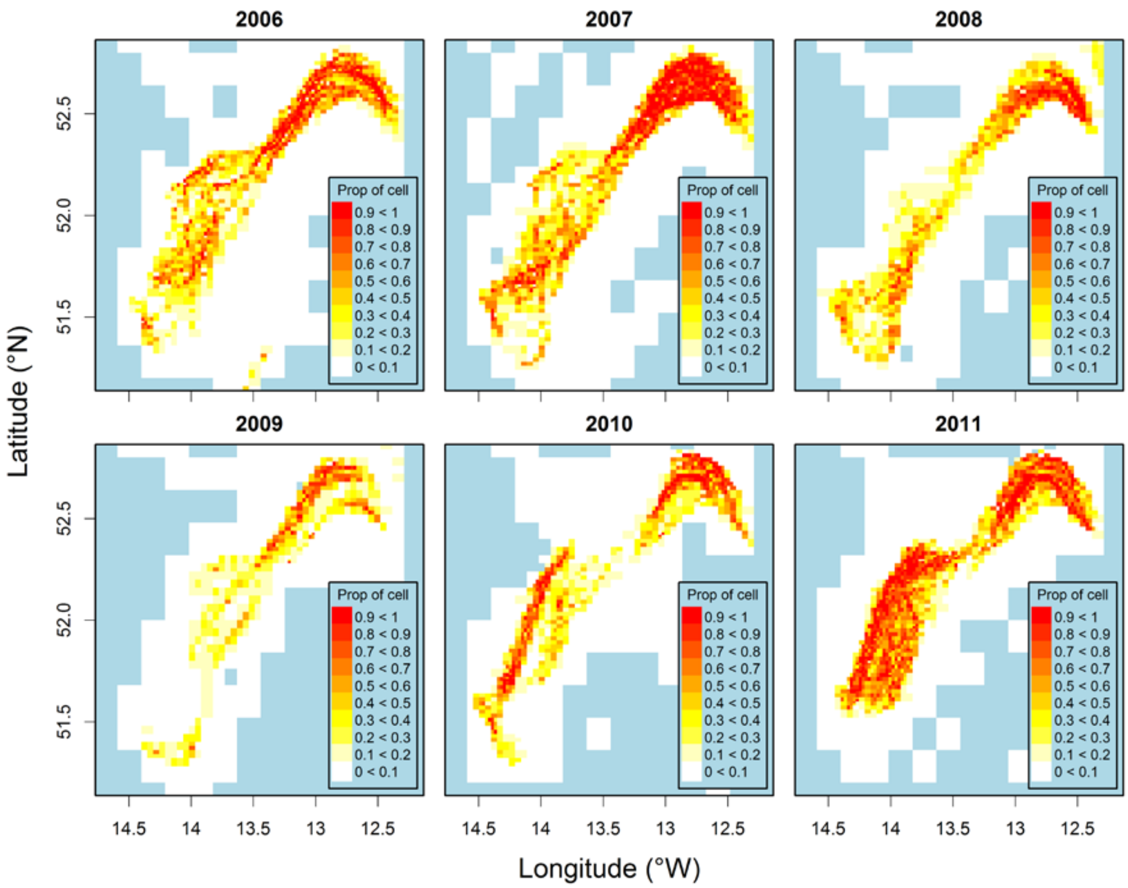

Figure 3b. The proportion of each grid cell that is impacted at least twice per year.

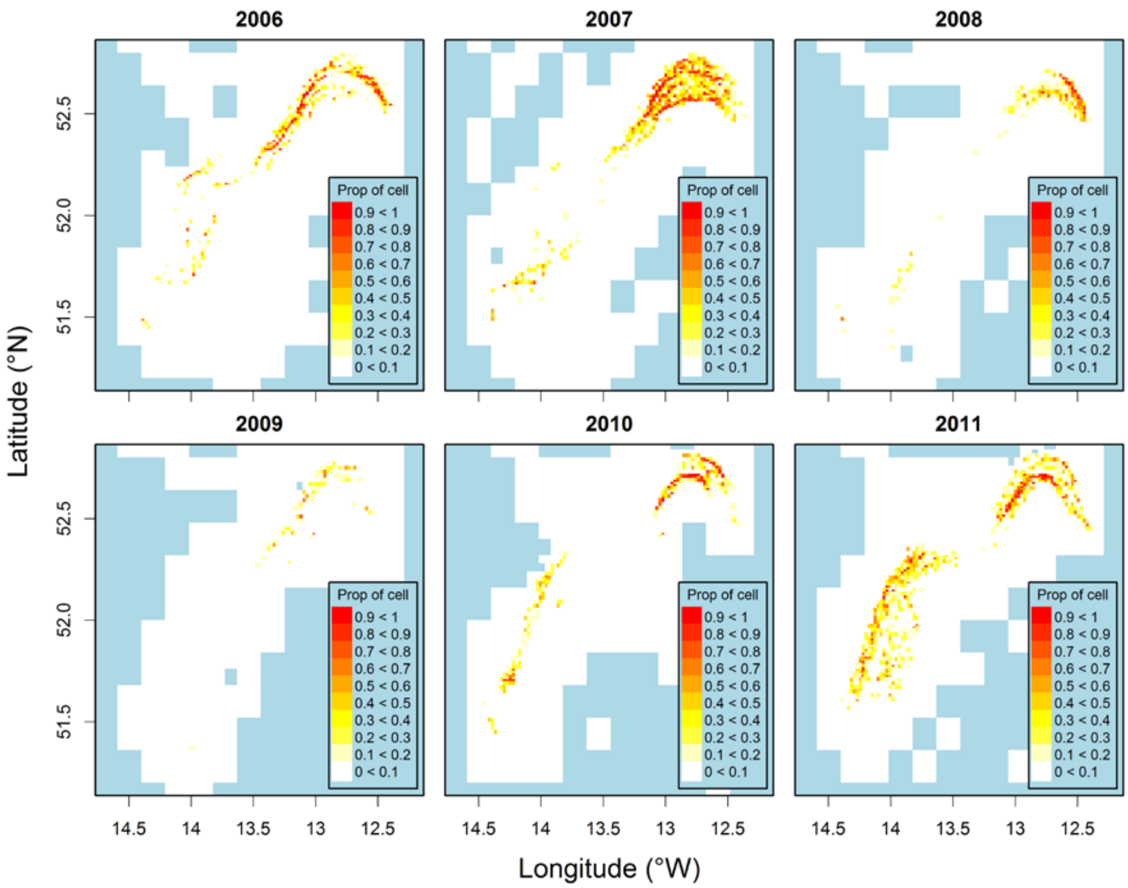

Figure 3c. The proportion of each grid cell that is impacted at least five times per year.

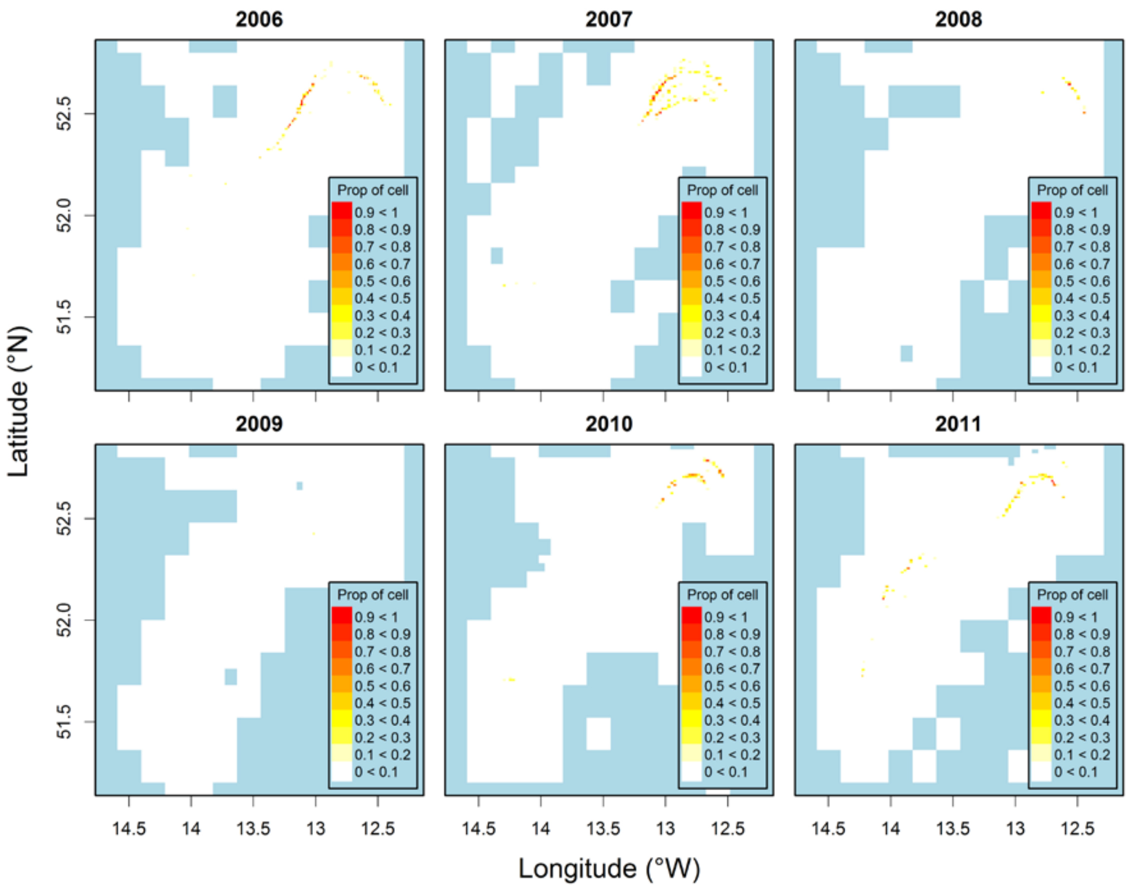

Figure 3d. The proportion of each grid cell that is impacted at least ten times per year.

Annex 4.7 Dispersal of *Nephrops* larvae from the Porcupine Bank

David O'Sullivan and Colm Lordan, Marine Institute, Galway, Ireland

Introduction

The Norwegian prawn, *Nephrops novegicus* is an important commercial species within Irish waters. Although widely distributed on the continental shelves of the Northeast Atlantic its overall distribution is discontinuous as the species depends on muddy seabed sediment which exist as disparate patches (see Figure 1). In wider European waters there are at least 30 different populations which are physically isolated from each other (Bell *et al*., 2006). One such population is found on the Porcupine Bank in association with a large (6929.6 km^2) spatially defined mud patch. The species occupy burrows within the muddy sediment. Eggs are incubated by females for about nine months over winter before larvae hatch, peaking in April–May, as protozoea and pass through three stages of development (Dickey-Collas *et al*., 2000a). The duration of the larval stages and thus the potential exposure to the prevailing hydrodynamic conditions is influenced by temperature (Dickey-Collas *et al*., 2000b). Re-settlement upon soft muddy sediment and the construction of burrows is crucial to survival.

The formation of cyclical gyres over *Nephrops* mud-patches have been postulated as being a key factor in the recruitment dynamics for this species. In the Western Irish Sea, the formation of a seasonal gyre coinciding with the peak release of hatched *Nephrops* protozoea (May) is thought to act as a retention mechanism (Hill *et al*., 1996), whereby larvae are held in the water column circulating over the mud-patch until resettlement occurs. This allows the now juvenile prawns the opportunity to colonize the mud patch ensuring survival. This reliance on hydrographic conditions has also been proposed for the Celtic Sea and Northeast Atlantic (Bailey *et al*., 1995 and Brown *et al*., 1995) and to a lesser degree similar oceanographic conditions have been described over the Porcupine Bank (White *et al*., 1998). It follows that yearly recruitment to the adult population depends on favourable environmental conditions and the strength of different year classes should, in theory, be related to ambient environmental conditions at the time of hatching.

The purpose of this study is to assess the potential dispersal field of planktonic *Nephrops* hatched on the Porcupine Bank using a larval transport model. The work will aid in the understanding of reproduction dynamics; the assessment of population structure and the degree of connectivity between populations all of which have important implications for fisheries management.

Material and methods

In order to determine the likely dispersal fields of *Nephrops* larvae from the Porcupine Bank a larval transport model, LTRANS, was used. LTRANS calculates the movement of particles that simulate *Nephrops* larvae and models their trajectories in three-dimensions enabling predictions about the extent of the dispersal field. The model was conditioned by observed hydrodynamic conditions, here the Regional Ocean Modelling System (ROMS), archived from January 2011–December 2012. This offered an opportunity to compare larval dispersal between 2011 and 2012. Furthermore, the differential release of particles to coincide with peak hatching times, described here as being 1st April, 1st May and 1st June, allowed differences in monthly temperature regimes and thus larval duration times to be observed. The Porcupine Bank *Nephrops* ground is well described and accurate seabed substrate maps exist showing the extent of the mud patch (Ref). Larvae can potentially be hatched from any location within the ground. The current study simulates 1000 larval hatching from one central location within the ground (13°46'31.485"W 51°57'5.992"N) at a depth of 450 m. The model assumes open water turbulence in both planes and further assigns a constant value for horizontal turbulence at 3m^2/sec. Table 1 contains any variable physical and biological inputs used during this study. A complete description of model functionality and design parameters of LTRANS v.2 are given by Schlag and North (2012) and North *et al*. (2008). The domain for the model is bounded by the following coordinates:

52°19’N 16°44’W

47°30’N 8°52’W

57°52’N 7°30’W

53°39’N 3°42’W

Sensitivity analysis tests to ensure biologically accurate, vertical outputs were conducted. Archived environmental data used to force the model can be overwritten by user defined inputs if necessary. Various artificial vertical advection rates, forcing larvae to remain in the upper 40 m of the water column, were simulated to investigate the importance of vertical distribution within the water column on ultimate horizontal dispersal. A depth profile for each model scenario was created. Elementary behaviour describing the effect of growth and larval swimming behaviour on dispersal distance was included to give a more realistic biological output. LTRANS assigns a linear increase in swimming speed over the duration of the particles 'life'. These variables could be tested at different swimming rates to determine the effect on dispersal.

Previous experimental studies on the developmental rate of reared *Nephrops* larvae were consulted in order to determine the relationship with temperature and hence a method of calculating the larval duration phase for the species. Dickey-Collas *et al.* (2000a) propose an exponential regression equation that describes stage I and stage II larvae quite well. Difficulties in continual successful rearing of larvae through to stage III resulted in those authors adopting an alternative stage III regression equation (from Smith, 1987). This study uses observed stage durations of larvae regressed against temperature using an exponential model derived from these laboratory experiments (Dickey-Collas *et al.*, 2000a; Smith, 1987).

Sea surface temperature (SST)s (SST's) recorded by offshore weather buoys were used in conjunction with these regression equations to determine the length of larval duration. A network of offshore weather buoys operated by the Marine Institute (see Figure for locations) continuously collects multiple data including sea surface temperature (SST's). Average monthly SSTs for the M6 buoy (53.07482°N 15.88135°W) were used in the estimation of *Nephrops* larval duration on the Porcupine Bank. Hatching times were chosen as 1st April, 1st May and 1st June for both 2011 and 2012. A larval duration for each stage (I, II and III) was calculated using the appropriate temperature and the results summed to give a total larval duration which was then used to parameterize the larval transport model. Average monthly temperatures for April, May and June in both 2011 and 2012 are given in Table 2 together with estimated larval durations. Stage I and Stage II larvae are deemed to occur within the same calendar month and thus subject to the same average temperature. The ultimate horizontal and vertical distribution of simulated *Nephrops* larvae from each scenario was viewed in a GIS (Arc 10).

Results

Nephrops larvae hatched on the 1st April, 2011 on the Porcupine Bank spent approximately 46.4 days in the water column before metamorphosing into juveniles and potential resettlement onto the mud patch. After this period of time using archived environmental conditions, 52.9% of the simulated hatchlings remained on, or over, the substrate necessary for successful re-colonization. Larvae were held at depth between 224–960 m with a discernible majority around 400 m. In a similar scenario modelled with artificial vertical manipulation (w = 0.004), all larvae occupied the upper 2 m surface layer of the water column but none remained over the porcupine bank ground. Instead the larvae had advected some distance to the southeast and toward the Celtic Sea. In 2012 this pattern for April hatchlings was broadly similar to 43% of larvae remaining over the mud-patch after 47.3 days. Only 4.3% of released larvae remained over the mud-patch when vertically manipulated.

This general trend is repeated for alternative release dates under archived conditions, resulting in some retention over the mud-patch, small horizontal dispersal fields and limited vertical advection. In 2011, 20% of larvae hatched in May and 12.7% of larvae hatched in June remained within the Porcupine ground, while in 2012 57.8% (May) and 41.5% (June) did so. In contrast, no larvae remained over the Porcupine ground in either 2011 or 2012 when manipulated to remain in the upper water column.

LTRANS shows a significant degree of sensitivity to interchangeable parameters as evidenced by a clear change in horizontal output in relation to vertical input. A positive vertical advection of 0.001 is enough to keep simulated larvae within 50 m of the surface, while an advection rate of 0.004 will keep larvae within the upper 2 m of the water column (Figure). Both of these rates produce similar southeasterly patterns of horizontal dispersal that retain <1% of larvae over the mud-patch. In contrast, 43% of larvae remain over the porcupine bank when the model is forced by natural environmental conditions. There was less sensitivity to alternate swim speeds. Three potential swimming velocities for mature larvae were compared 0 mm/s, 15 mm/s and 30 mm/s. No difference was observed in horizontal output or retention between 0 and 15 mm/s with 50.3% remaining over the bank. Mature larvae swimming at 30 mm/s were more likely to be outside the boundaries of the bank and only 43% were retained.

Discussion

Temperature is an important driver regulating the larval stage durations of planktonic crustacea with considerable variation in the developmental rate being observed when larvae are subject to various temperature regimes (Dickey-Collas *et al.*, 2000a; Smith, 1987). Most observations on the larval-developmental rate of *Nephrops* are from experimental research under laboratory conditions. The majority of research suggests that an exponential relationship accounts for most variation in the stage duration to temperature relationship. Many of these studies cite difficulties in extrapolating experimental research to wild populations. These include a limited survival rate of reared larvae, the applicability of results to wild populations and the differences that may exist between geographically distinct wild populations. Differences also exist when using an integrated water column temperature and a surface temperature. In this case only data for SST's exist which may not accurately capture water temperature at depth. Despite the aforementioned caveats these equations were considered reliable and agreed with Dickey-Collas *et al.* (2000a) giving a robust estimation of the larval duration of the three zoeal stages.

Initial tests indicate that the ultimate vertical distribution of the larvae forced by archived environmental conditions did not accurately capture the preferential distribution of *Nephrops* larvae in the upper layer (20–30 m) of the water column (Bailey *et al.*, 2000). Our results show the majority of larvae at ~400 m depth. It is unlikely that this is the case in reality as larvae are thought to rise to the surface to take advantage of more favourable feeding conditions and warmer temperature. Such conditions may be enhanced in spring by the formation of a Taylor Column structure, a dome of warm stratified cyclical surface flow (White *et al.*, 1998), which may also act as a retention mechanism over the bank area. This combination potentially allows larvae to move through their larval developmental phases as quickly as possible while retaining an advantageous position over the mud-patch once larval maturation is complete. As described no larvae forced under natural conditions were observed in the upper 300 m of the column. It is unlikely that these particles were prevented from entering the upper surface layer by the formation of a stratified dome but it cannot be discounted. However, when the advection rate was artificially manipulated to force the larvae into the desirably upper surface layer, a much larger horizontal dispersal area was observed and very few larvae remained in the vicinity of the mud-patch after being forced by surface currents, themselves being forced by windstress.

The results of swimming speed on larval dispersal were less conclusive. It would be expected that no swimming whatsoever would result in a smaller dispersal field. This study found no difference in the dispersal of larvae swimming at 0 and 15 mm/s. LTRANS assumes turbulence horizontally and vertically to randomly diffuse particles and it is possible that this effect masked any swimming behaviour. A doubling of swimming speed to 3 mm/s only accounts for a 7.3% increase in retention. Again, a larger effect might be expected if larvae are moving strongly through the water in conjunction with prevailing oceanic currents. Further tests on the sensitivity of these parameters are needed as the relevance of any biological output from a larval transport model depends on the accuracy governing the input assumptions and the sensitivity to variable parameters.

The formation of a cyclic gyre known as a Taylor Column structure has been observed over the Porcupine Bank previously (White *et al*., 1998) but its occurrence is not annual and the strength of the gyre, linked to windstressings and deep-water upwellings is highly variable. The findings in this study indicate some retention mechanism being in place in both 2011 and 2012, with the latter having a higher mean retention (47.4% compared to 30.6%). This suggests that 2012 may prove to be a better year for recruitment to the adult *Nephrops* population in the Porcupine Bank. Future observation of the year classes within the adult population may be able to further validate the applicability of the model and its biological parameters. The potential of onward dispersal to other *Nephrops* grounds was not seen in the present study which tentatively suggests a closed isolated population structure existing in the Porcupine Bank. This is in agreement with Hill *et al*. (1996), where the authors note non-existent exchanges between populations except potential connectivity between neighbouring stocks during larval dispersal. However our assumptions are based on assumed biological parameters and archived environmental conditions for only 2011 and 2012. It may be possible for certain environmental conditions to encourage the formation of a cyclical gyre in some years thereby isolating populations while contributing larvae to other stocks in other years. Isolated populations with a low genetic diversity are prone to stochastic events so limited larval connectivity between stocks is not unlikely.

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Table 1. Variable biological and physical LTRANS parameters used during the present study (see also Schlag and North, 2008).

BIOLOGICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS	
No. of Particles	1000	Boundary	False
Hatching Dates	1st April, 1st May, 1st June	External time-step	10 800 sec
Swim Speed at Maturity	15 / 30 mm/s	Internal time-step	400 sec
Mortality	95%	Horizontal Turbulence	True
Age at swim start	10 days	Vertical Turbulence (3 m–2/s)	True

Table 2. Regression parameters for ln (stage duration) vs. temperature relationship for *Nephrops* larvae in this study.

	SLOPE	SE (SLOPE)	INTERCEPT	SE (INTERCEPT)	SOURCE
I	-0.163	0.006	4.283	0.064	Dicky - Collas *et al*. (2000a)
II	-0.161	0.013	4.51	0.17	Dicky - Collas *et al*. (2000a)
III	-0.113	-	4.188	-	Smith (1987)

Table 3. Average monthly sea surface temperature (SST) (°C) recorded by the M6 weather buoy and the subsequent calculation of *Nephrops* larval stage duration (days) as used within larval transport model, LTRANS.

YEAR	MONTH	MEAN TEMP (°C)	STAGE I	STAGE II	STAGE III	TOTAL (DAYS)
2011	April	10.9	12.3	15.7	18.4	46.4
	May	11.3	11.5	14.7	17.7	43.9
	June	11.6	10.9	14	17.7	42.6
2012	April	10.7	12.6	16.2	18.5	47.3
	May	11.2	11.6	14.9	14.8	41.3
	June	13.2	8.4	10.8	14.8	34

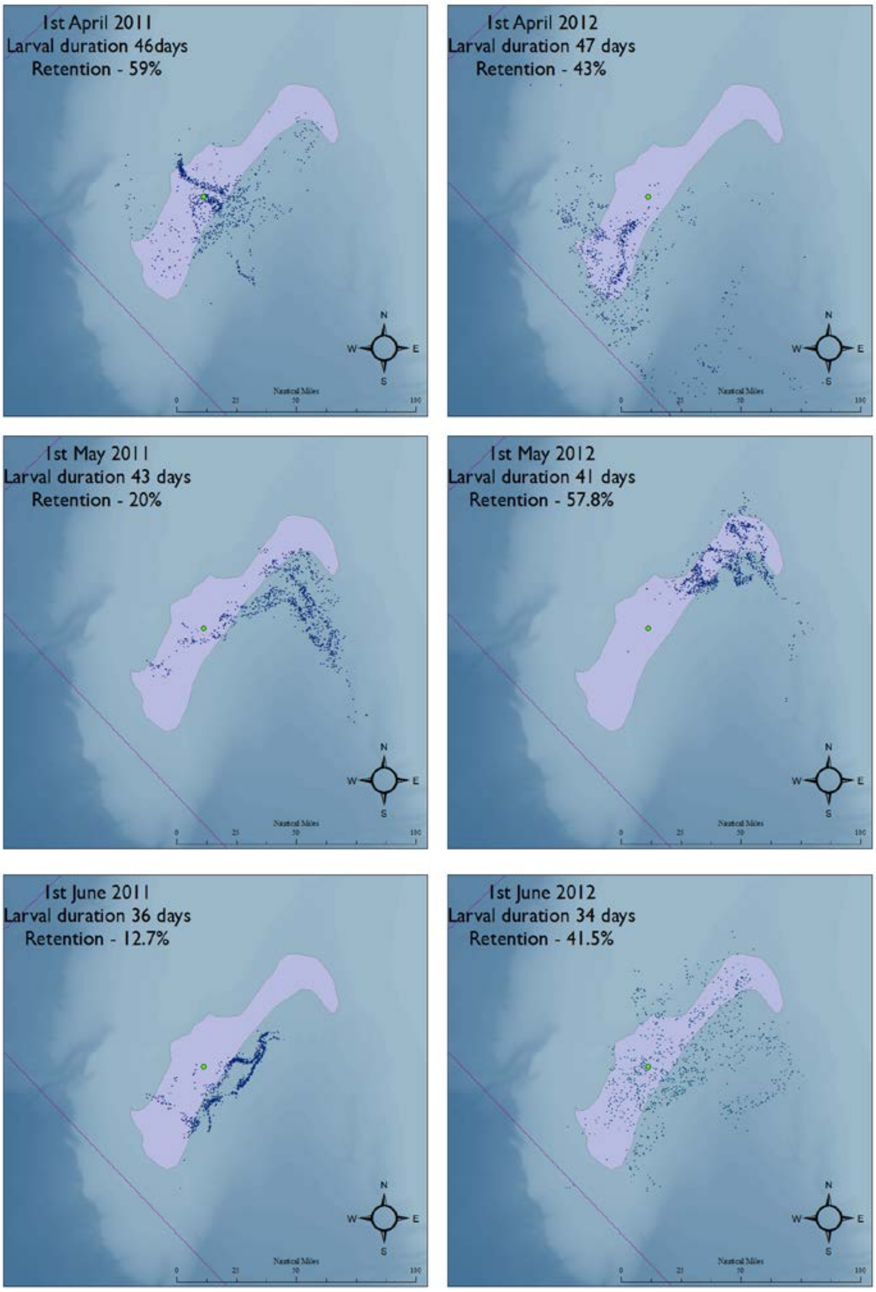

Figure 1. The extent of *Nephrops* larval dispersal over the Porcupine Bank from three release dates (1st April, May and June) and tracked with archived environmental conditions from 2011 and 2012 by LTRANS. Percentage of larvae from each simulation retained over the mud-patch is shown. Green dot indicates initial hatch location (13°46'31.485"W 51°57'5.992"N) at 450 m.

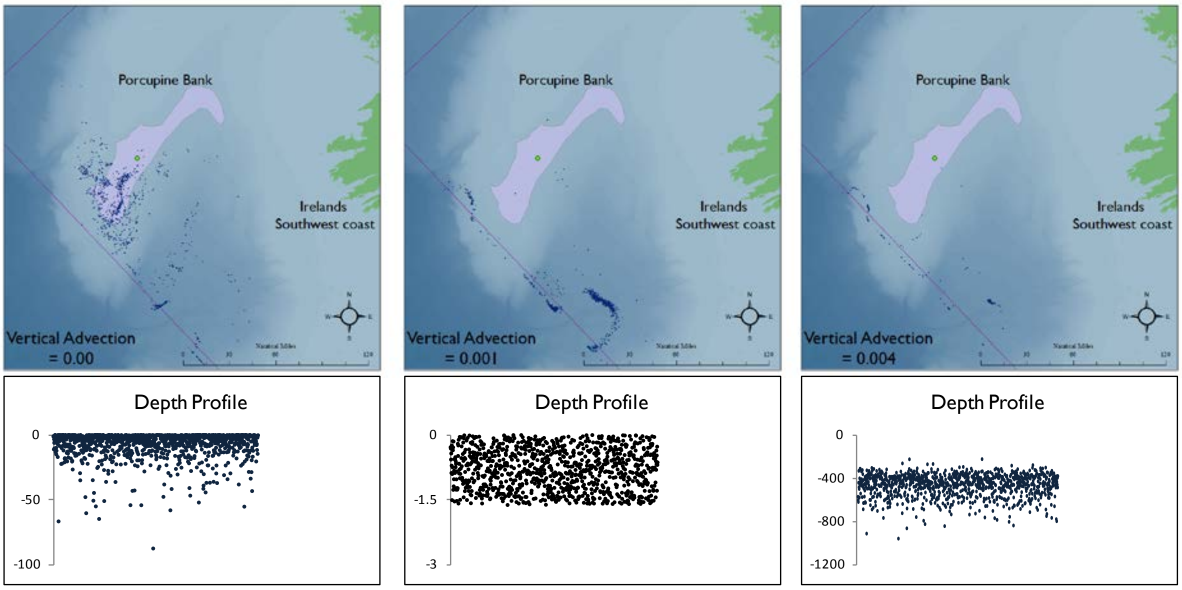

Figure 2. The effect of increased vertical advection on the ultimate horizontal dispersal of *Nephrops* larvae hatched on April 1st 2012. Depth profiles showing depth distribution (m) of larvae within the water column after 47 days. Note scales and depth ranges differ.

Appendix

LTRANS was designed to predict the movement of particles based on advection, turbulence and swimming behaviour. It includes an external time-step of model output and an internal time-step of particle movement. The external time-step is set at 10 800 seconds as hydrodynamics are archived every three hours (3*3600), whilst the internal time-step is adjustable. As the model has a resolution of ~2 km, it may take multiple time-steps for a particle to move across a grid cell. This study used an internal time-step of 500 seconds offering a compromise between acceptable run-time whilst also ensuring that each time-step occurs within the appropriate grid cell.

Nephrops are advected differentially through horizontal and vertical diffusion. This pelagic part of the life cycle is governed equally by physical and biological factors as the larvae are carried passively by the prevailing currents.

Annex 5: Stock Annexes

Stock Annex for FU16, Porcupine Bank

Stock	Porcupine Bank *Nephrops* (FU16)
Date	March 2013 (WK*NEPH* 2013)
Revised by	Colm Lordan and Jennifer Doyle

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. The boundary use to delineate the edge of the Porcupine *Nephrops* ground was based a manually defined poloygon around *Nephrops* directed VMS fishing activity data between 2006–2011 Table A.1.1. *Nephrops* directed activity was defined for VMS pings where >30% of daily operational landings was reported to be *Nephrops* using the methods described in Gerritsen and Lordan (2011). The total area estimate was 7100 km^2 (Lordan *et al*., 2012). The precision of the estimate is in the order of 1–2% depending on geographic projection. This is likely to be an underestimate of the total area of the stock since there are minor groundfish survey catches and fishing pings outside this poloygon.

At moderate and high densities adult *Nephrops* probably only undertake very small-scale movements (a few 100 m) due to the territorial nature of the animals. At low densities, as observed on the Porcupine Bank, there may be some movement of individuals around the ground. *Nephrops* have a larval phase which is likely to be in to order of 30–50 days at the temperature regimes experience around the Porcupine Bank. The Porcupine *Nephrops* ground is quite geographically quite isolated from other areas. Recent practical tracking modelling supports the working hypothesis that advection of larvae into FU16 from other areas is unlikely.

The Functional Unit for assessment includes some parts of the following ICES Divisions VIIb,c,j,k. The fishery data for this includes the following ICES Statistical rectangles: 31 D5–D6; 35–32 D5–D8 (Figure A.1.1).

A.2. Fishery

France

The French fishery on the Porcupine Bank commenced in the late 1960s. The fishery was an extension of the French *Nephrops* fishery in Division VIIg–h and was described in detail in the 1999 WG*NEPH* report (ICES, 1999a). Length–frequency data show that the French fleet only landed very large *Nephrops* from this FU. WG*NEPH* in 2002 explored the spatial distribution of French landings between 1999–2000 by ICES rectangle and this analysis showed the majority of landings were from the south of the Porcupine Bank.

Ireland

The Irish fishery developed in the late 1980s. Historically the Irish fishery was very seasonal taking place mainly between April and July. Landings for the remainder of the year were minimal. Irish vessels landed both whole graded prawns and tails depending on markets. Before 2003 the sizes of the Irish landings were significantly smaller than those for the French and Spanish fleets. Freezing of catches at sea has become increasingly prevalent since 2006 and several vessels now participate in the fishery throughout the year. There has also been shift towards mainly targeting the larger more valuable *Nephrops* which are usually caught in lower volumes (Lo. The Irish vessels are mainly between 20 and 35 m in total length and they use twin-rig trawls with >80 mm mesh.

Fishing can be weather-dependent (particularly for the smaller vessels), with trip duration varying between seven and 21 days. 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 recent spatial distribution of the Irish fishery is shown in Figure A.1.1.

Spain

The Spanish fishery in the Porcupine area developed in the 1970s and landings peaked in the 1980s. The fishery is a typical multispecies fishery, targeting different demersal species, amongst which is *Nephrops*. There are four Spanish métiers in Porcupine Bank, OTB_DEF_100-119_0_0 (bottom trawl directed to hake), OTB_DEF_70-99_0_0 (bottom trawl directed to flat fish), LLS_DEF_0_0_0 (bottom longline) and GNS_DEF_120-219_0_0 (gillnet directed to hake). The FU 16 bottom-trawl fleet consists of 40 vessels (2011), is composed of side trawlers and is part of the so-called '300 fleet' in the Adhesion Treaty of Spain to the EEC in 1986. Within this fleet, two components can be distinguished: one consisting of vessels directed to hake (OTB_DEF_100-119_0_0) and the other directed to flat fish (OTB_DEF_70-99_0_0). The average duration of their trips is 15 days, of which 10–12 are actual fishing days.

18 vessels were directed to hake (OTB_DEF_100-119_0_0) in FU 16 in 2011. They have an average LOA of 36.5 m and an average power of 500 kW, use a 100–120 mm mesh size. The major landing port is A Coruña, but also Vigo, Celeiro, Ondarroa, Castletown Bere, Lochinver and Dingle. The bycatch are other demersal fish (monkfish, megrims) and *Nephrops*. This métier includes also the trips directed to *Nephrops* (80 mm mesh size) due to the difficulties of its disaggregation, overall since the close season implementation (Reg. UE no 23/2010). Hake account for the 20% of landings of the métier and *Nephrops* the 2%. In 2011 only three vessels have some trips (15%) directed to *Nephrops* in FU 16, the rest of their trips (85%) were directed to hake.

22 vessels were directed to flat fish (mainly megrims and monkfish) (OTB_DEF_70-99_0_0) in FU 16 in 2011. They have an average LOA of 34.5 m and an average power of 415 kW, use a 80–100 mesh size. The major landing port is Vigo, but also Castletown Bere. Megrims account for the 26% of landings of the métier and *Lophius budegassa* the 15%.

UK Scotland

A number of large Scottish *Nephrops* vessels have participated in the fishery during summer since 2002. These vessels have accounted for approximately 10–15% of the total landings in recent years.

UK England and Wales

Vessels are all around 28–33 m in length and appear to be flag vessels where 50–60% landings are into Spain. The fleet has reduced a lot in recent years from 27 vessels in 2000, 15 vessels in mid-2000s to three vessels in 2011.

Technical measures

The following TCMs are in place for *Nephrops* in VII (excluding VIIa) after EC 850/9 in operation since 2000:Minimum Landing Sizes (MLS); total length >85 mm, carapace length >25 mm, tail length >46 mm. Although it is legal to land smaller prawns from this fishery, marketing restrictions imposed by producer organizations in France mean smaller *Nephrops* (<35 mm CL or 115 mm whole length) are not retained in this fishery.

The mesh size restrictions apply to towed gears in VIIb–k targeting *Nephrops* and are given in Section 7.1. Vessels mainly used 80–99 mm mesh to target *Nephrops* on the Porcupine Bank.

Closed area restrictions

A seasonal closed area has been in place since May 2010. The closed area is shown in the map below and the specific coordinates and conditions of the closed area are given below. This closed area accounts for ~75% of the area on the bank where *Nephrops* are fished. According to Article 11 of EC Reg 43/2012 "*It shall be prohibited to fish or retain on board any of the following species in the Porcupine Bank during the period from 1 May to 31 July 2012: cod, megrims, anglerfish, haddock, whiting, hake, Norway lobster, plaice, pollack, saithe, skates and rays, common sole and spurdog.*"

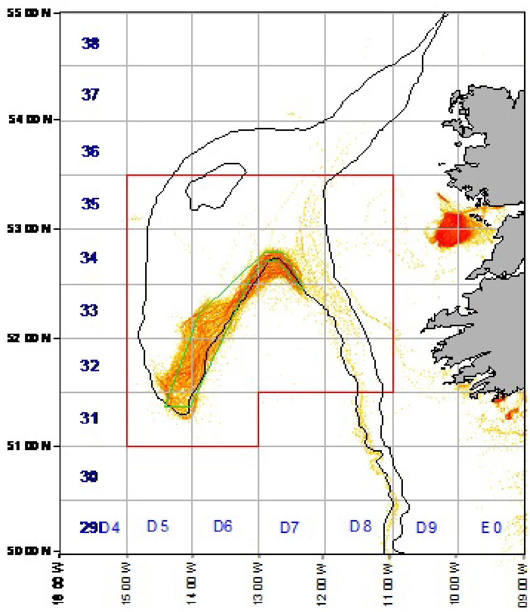

Figure A.1.1. The FU16 outlined by the red line. The closed area from 1st May to 31st July from 2010 to 2012 is shown with a green line. Irish *Nephrops* directed fishing effort between 2006–2009 derived from integrated VMS and logbook information is shown as a heat map.

In the past TACs and quotas applied to the whole of VII so the FU16 fishery has not been restricted. In 2011 an "of which clause" was implemented in the TAC regulation specifically for the Porcupine Bank in 2011 for the first time of a limit of 1260 t.

TAC in 2012

Species: Norway lobster *Nephrops norvegicus*		**Zone:** VII (NEP/07.)
Spain	1 306 (1)	
France	5 291 (1)	
Ireland	8 025 (1)	
United Kingdom	7 137 (1)	
Union	21 759 (1)	
TAC	21 759 (1)	Analytical TAC Article 11 of this Regulation applies.

(1) Special condition: of which no more than the following quotas may be taken in VII (Porcupine Bank – Unit 16) (NEP/*07U16):

Spain	380
France	238
Ireland	457
United Kingdom	185
Union	1 260

Council Regulation (EU) No 43/2012 of 17 January 2012 fixing for 2012 the fishing opportunities available to EU vessels for certain fish stocks and groups of fish stocks which are not subject to international negotiations or agreements.

A.3. Ecosystem aspects

Physical oceanography

The *Nephrops* stock on the Porcupine Bank is distributed on mud patches in relatively deep waters 260–570 m (Figure A.3.2). Productivity of deep-water *Nephrops* stocks is generally lower that those on the shelf although individual *Nephrops* grow to relatively large sizes. The formation of a cyclic gyre known as a Taylor Column structure has been observed over the Porcupine Bank previously (White *et al*., 1998) but its occurrence is not annual and the strength of the gyre, linked to windstressings and deep-water up-wellings which is highly variable. This gyre does provide an important mechanism for the retention of pelagic eggs and larvae of the various marine species spawning in the area. (Mohn *et al*., 2002). It is not known if this feature retains *Nephrops* larvae over suitable habitat on the Porcupine Bank. But work is underway to determine the likely dispersal fields of larvae from the Porcupine Bank using a larval transport model, LTRANS. This model calculates the movement of particles that simulate *Nephrops* larvae trajectories in three-dimensions enabling predictions about the extent of the dispersal field.

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. The substrate datasets from the Irish National Seabed Survey (INSS) were collated and merged under the MeshAtlantic project (http://www.meshatlantic.eu/) using a modified Folk classification. This resulted in a substrate polygon of the Porcupine Bank. From this project the mud patch of the *Nephrops* grounds is clearly visible (Figure A.3.1). There is insufficient sediment and burrow density data to explore relationships between burrow density and sediment for this area.

Bathymetry

The Porcupine Bank is a continental block partly split off from the Irish shelf by a failed rift where it separates the Rockall Trough from the Porcupine Seabight (Dorschel *et al*., 2010). It is characterized by gentle east and steep south, west and northwest slopes and the shallow flat region of the bank show widespread iceberg ploughmarks. The bathymetry data for the Porcupine Bank was obtained from INSS seabed mapping programmes (www.infomar.ie/) and is show in Figure A.3.2.

B. Data

B.1. Commercial catch

Commercial landings data are supplied by Ireland, France, Spain and the UK. The quality of historic landings data is not well known but they are perceived to be reasonably accurate. The time-series of French landings commences in the mid-1960s. Spanish data commences in 1972 and Irish landings data commences in 1989.

Landings statistics for the Irish fleet are obtained from EU logbooks. Vessels record daily retained catches in operations and make a declaration of total landings on return to port. In 2011 an "of which clause" was implemented in the TAC regulation specifically for the Porcupine Bank. This has resulted in restrictive vessel quotas in Ireland. An area misreporting correction has been applied to calculate Irish landings in 2011 (ICES, 2012). Since 2012, most vessels in the fleet have been using electronic logbooks (EC Regulation 1224 of 2009 and 404 of 2011). Vessels are required to electronically report catches on board in each 24 hour period so this should make area misreporting more risky for the vessels.

Similarly landings from UK Scotland and England, Wales and Northern Ireland are available from the logbooks. Landings data have been supplied separately for Scottish vessels landing in Scotland or abroad from all UK vessels landing into England and Wales and UK England, Wales and Northern Ireland landings abroad.

Landings from France are obtained from EU logbooks. In Spain aggregated sales notes from port sampling are used to estimate the landings not official statistics.

Sampling data

Historical sampling data for each country are presented in Table B.1.2. Length compositions of annual landings are available from Spain (1986–2009), France (1995–2007) and Ireland (1995–2005 and 2008–2011). There has been a general decline in sampling levels since the mid to late 2000s due to decreasing volumes of landings and higher proportions of the landings being graded and/or frozen at sea. No sampling was possible in 2006 and 2007 for Ireland due to the withdrawal of cooperation with scientific sampling programmes by the fishing industry. Sampling in Ireland resumed in 2008 but sampling levels were low initially due to problems in accessing frozen graded landings. Since 2010 Irish landings length distributions have be reconstructed using data on the size distribution of each frozen grade and volumes of each frozen grade landed.

The number of trips and hauls sampled for discards by Ireland are presented in Table B.1.3. Discarding of *Nephrops* during these trips was negligible mainly limited to few small and damaged individuals. Fish and other bycatches in the fishery have been collected by on board observers since 1994. Discarding by the *Nephrops* trawl fishery is around 50% of the total catch by weight. The main species that are discarded by weight are blue-mouth redfish, blue whiting and argentines (Anon., 2011).

B.2. Biological

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

Length–weight

At WK*NEPH* new length–weight parameters were available based on Spanish sampling carried out between October 2001–January 2003. These parameters were based on fresh landings sampled in the port and should be used until such time as better estimates become available.

	A	B	Size range	Sample Size
Females	0.0009	2.9131	25.4–59.5	263
Males	0.0002	3.2736	29.8–69.7	372

Natural mortality

A natural mortality rate of 0.2 was assumed for all age classes and both sexes. The male M is lower than that typically used for most other *Nephrops* stocks (normally 0.3). The accuracy of these assumptions is unknown but some sensitivity testing on the impact to F reference points has been carried out (Lordan *et al*., 2012).

Maturity

Previous studies by Fariña and González Herraiz (2001) determined the L_{50} of females at 26.2 mm CL using a macroscopic visual maturity scale. An updated analysis was available at WK*NEPH* 2013 and the female L_{50} was estimated as 28.7 weighted average from 2001–2012 survey data. The same L_{50} was assumed for males because different metrics previously investigate tend to give different estimates of this parameter (González Herraiz, 2011)

Proportion of F and M prior to spawning was specified as zero to give estimates of spawning–stock biomass on 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 negligible discard rates observed to date, no estimate of discard survival is provided.

B.3. Surveys

IBTS Groundfish Survey

The longest time-series of fishery-independent source of data is from the Spanish Porcupine trawl survey 2001–2012 (SpPGFS-WIBTS-Q4). The survey is carried out annually in September when *Nephrops* catchability is quite low, particularly of adults. The gear used on this survey is the Baca trawl gear. This survey provides an index of recruitment and cpue for this stock. Further information on this survey is provided in the IBTS report (ICES, 2012c) and in previous IBTS reports. Haul positions of the survey series are shown in Figure B.3.1.

Irish Fisheries Science Research Partnership (IFSRP) Trawl Survey

An Irish Fisheries Science Research Partnership (IFSRP) survey was developed in collaboration with the Irish fishing industry to obtain data from the closed area in 2010–2012. Haul positions of the survey series are shown in Figure B.3.4. The IFSRP trawl survey is too short (with changes in coverage, gears and vessels) to draw an inference about cpue changes reflecting changing stock abundance. The survey does however provide very useful data on population structure across the ground as well as data on grade structure and maturity-at-length. There is a significant difference in catch rates between the IFSRP survey in July and the SpPGFS-WIBTS-Q4 in September using as similar net. This is likely to be related to behaviour of *Nephrops* where the adult stock is more active on the surface in July compared with September.

UWTV Survey

In 2012 Ireland conducted the first underwater television survey (UWTV) on the Porcupine Bank. The survey was based on a randomized fixed isometric grid design. The methods used during the survey were similar to those employed for UWTV surveys of *Nephrops* stocks around Ireland and elsewhere and are documented by WKNEPHTV (ICES, 2007) and SGNEPS (ICES, 2009 and 2010).

UWTV relative to absolute conversion factors

In order to use the survey abundance estimate as an absolute it is necessary to correct for potential biases. For the Porcupine Bank the field of view of the camera was 0.75 m and expert judgment of the mean burrow diameter was in the range of 0.55–0.65 m. Using the simulation approach suggested by Campbell *et al.*, 2009 the estimated edge effect bias was in the range of 1.24–1.28. This seems low compared with other areas but it is based on the best judgement of burrow diameter from the footage. In future it may become possible to quantitatively estimate burrow diameter from mosaics of the footage from this and other areas. Burrow detection rates were thought to be relatively high due to good water clarity and few other burrow systems of similar size. Burrow identification could be slightly overestimated since a few fish and squat lobsters were observed at burrow entrances. The proposed cumulative correction factor for the area was 1.26 (Table below). When compared to with the correction factors applied in other areas it is quite close to the average used on other grounds.

The biases associated with the estimates of *Nephrops* abundance in the Porcupine Bank are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU16: Porcupine Bank	2012	1.26	0.95	1.05	1	1.26

The survey and results are described in detail (Lordan *et al.*, 2012) and Figure B.3.3 shows the completed stations on 2012 UWTV survey.

B.4. Commercial cpue

In the past the *Nephrops* fishery on the Porcupine Bank was both seasonal and opportunistic with increased targeting during periods of high *Nephrops* emergence and good weather. Freezing of catches at sea has become increasingly prevalent since 2006 and the fishery now operates throughout the year, mainly targeting larger more valuable *Nephrops* in lower volumes. Figure B.4.1 shows the historic seasonality of the Irish fleet and the recent throughout the year pattern is evident from 2006. Effort and lpue/cpue data are generally not standardized, and hence do not take into account vessel capacity, efficiency, seasonality or other factors that may bias perception of lpue/cpue and abundance trends over the longer term. WD12, Gerritsen and Lordan, ICES 2011) modelled lpue over the available time-series including vessel, spatial and temporal explanatory variables. It was concluded that it remains possible that the long lpue trend is biased in the past and not reflective of stock abundance given the observed differences in size structure throughout the ground. However, while targeting behaviour and fleet composition has changed significantly over time this does not significantly alter the long-term trends.

Irish and French effort is in hours and Spanish effort is power adjusted and is reported in thousands of day*BHP/100.

The available effort time-series are summarized below:

Country	First year of effort data	Units	Comment
France	1983	Hours	For trips where *Nephrops* constituted 10% of the landed value
Ireland	2005	Hours	For trips where *Nephrops* constituted 30% of the landings in weight
Spain	1971	ay*BHP/100 (x1000)	

A new VMS based effort time-series has been calculated for the Porcupine Bank. This includes all the effort of vessels at trawling speed within the known area of the *Nephrops* grounds (Table B.4.1.).

C. Assessment: data and method

Model used: UWTV Based Approach to generate catch options

In 2009 WK*NEPH* debated the use of the surveys as either an absolute measure of abundance or a relative index (ICES, 2009a). Ultimately this led to a consensus that bias corrected survey abundance estimates could be used directly in the formulation of catch advice. Two modelling approaches were used to estimate sustainable stock specific Harvest Ratio reference points; SCA (a separable LCA model Bell) and Age Structured Simulation model (Dobby) (ICES, 2009a).

Software used: Age Structured Simulation model (Dobby) per recruit analysis in r.

Model Options chosen: An LCA should be fitted to recent observed removals length distributions. Normally a three year average is used but this is depended on the quality of the available data. Lordan *et al*., 2012 only had reliable 2010–2011 data available. The LCA analysis is used to estimate fishery selection using a logistic curve but other models could be explored in future. Relative catchability of females in the fishery is also estimated. This outputs are used as the inputs to the per recruit analysis.

D. Catch option table based on UWTV surveys

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
$F_{0.1}$	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
F_{max}	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
$F_{current}$	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Interim reference points were estimated by Lordan *et al.*, 2012. These should be updated when new data become available.

Porcupine Bank *Nephrops* estimated Per Recruit Reference Points and associated harvest ratios.

			FBAR(35–50 MM)		HR (%)	SPR (%)		
		Fmult	M	F		M	F	T
$F_{0.1}$	M	0.15	0.133	0.039	4.2	41.4	77.4	54.0
	F	0.65	0.575	0.170	11.2	12.7	43.9	23.6
	T	0.19	0.168	0.050	5.0	35.2	73.0	48.4
F_{max}	M	0.29	0.257	0.076	6.8	25.3	63.7	38.8
	F	1.61	1.425	0.421	17.8	6.2	25.0	12.8
	T	0.58	0.513	0.152	10.5	14.0	46.7	25.4
$F_{35\%SpR}$	M	0.2	0.177	0.052	5.2	33.9	71.9	47.2
	F	0.96	0.850	0.251	13.9	9.2	34.9	18.2
	T	0.35	0.310	0.091	7.7	21.6	59.2	34.8

H. Other issues

H.1. Historical overview of previous assessment methods

An experimental age structured assessment for this stock was carried out by the *Nephrops* WG in 1993 (ICES, 1993), in 2003 (ICES, 2003) and by the WGHMM (ICES, 2005). 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.

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Table A.1.1. Porcupine Bank *Nephrops* ground boundary based on VMS activity for Irish vessels between 2006–2011.

Decimal Latitude	Decimal Longitude	Easting	Northing
52.51	-13.27	5819172	617406.5
52.37	-13.4	5803397	608929.4
52.35	-13.6	5800890	595357
52.35	-13.76	5800691	584459.5
52.12	-14.17	5774710	556827
52.01	-14.16	5762484	557653.1
51.7	-14.35	5727872	544920.3
51.66	-14.45	5723367	538043
51.68	-14.52	5725557	533186.6
51.7	-14.57	5727760	529716.6
51.63	-14.56	5719979	530454.6
51.46	-14.4	5701152	541683.9
51.4	-14.41	5694473	541042.9
51.28	-14.23	5681244	553704.4
51.24	-14.14	5676866	560033.5
51.26	-14.04	5679176	566985
51.32	-13.97	5685915	571775.6
51.62	-13.83	5719424	580998.2
51.8	-13.72	5739569	588262
51.99	-13.47	5761032	605055.7
52.13	-13.33	5776813	614310
52.36	-13.13	5802726	627338.5
52.53	-12.74	5822390	653301
52.55	-12.64	5824832	660010.5
52.53	-12.59	5822720	663474.3
52.41	-12.39	5809847	677520.7
52.38	-12.34	5806635	681043.7
52.42	-12.32	5811134	682239.7
52.47	-12.32	5816694	682033.4
52.57	-12.35	5827739	679587.6
52.67	-12.44	5838639	673094.4
52.77	-12.57	5849455	663930.4
52.81	-12.68	5853659	656367.2
52.82	-12.8	5854516	648246.3
52.8	-12.92	5852051	640225.5
52.76	-13.01	5847431	634281.8
52.59	-13.15	5828271	625321.4
52.51	-13.27	5819172	617406.5

Table B.1.1. Historical Sampling by country for FU16 *Nephrops* Porcupine Bank.

Year	Spain		France		Ireland		Source
	Number	Type	Number	Type	Number	Type	
2012	0	0	0		3	Graded Landings	WKNEPH 2013
2011	0	0	0		2	Graded Landings	WGCSE 2012
2010	0	0	0		3	Graded Landings	WGCSE 2011
2009	5	Port Landings	0		2	Port Landings	WGCSE 2010
2008	2	Port Landings	0		3	Port Landings	WGCSE 2009
2007	5	Port Landings	0		1	Port Landings	WGHMM 2008
2006	28	Port Landings	4	Port Landings	0		WGHMM 2007
2005	38	Port Landings	6	Port Landings	17	Port Landings	WGHMM 2006
2004	30	Port Landings	6	Port Landings	14	Port Landings	WGHMM 2005
2003	32	Port Landings	0		5	Port Landings	WGHMM 2004
2002	32	Port Landings	3	Port Landings	11	Port Landings	WGNEPH 2003
2001	55	Port Landings	3	Port Landings	12	Port Landings	WGNEPH 2003
2000	61	Port Landings	4	Port Landings	0		WGNEPH 2003
1999	60	Port Landings	4	Port Landings	9	Port Landings	WGNEPH 2003
1998	60	Port Landings	5	Port Landings	9	Port Landings	WGNEPH 2003
1997	60	Port Landings	3	Port Landings	10	Port Landings	WGNEPH 2003
1996	56	Port Landings	6	Port Landings	7	Port Landings	WGNEPH 2003
1995	60	Port Landings	1	Port Landings	14	Port Landings	WGNEPH 2003
1994	36	Port Landings	0		0		WGNEPH 2003
1993	37	Port Landings	0		0		WGNEPH 2003
1992	36	Port Landings	0		10	Port Landings	WGNEPH 1999
1991	36	Port Landings	0		16	Port Landings	WGNEPH 1999
1990	36	Port Landings	0		35	Port Landings	WGNEPH 1999
1989	35	Port Landings	0		0		WGNEPH 1999
1988	29	Port Landings					González Herraiz, 2011
1987	20	Port Landings					González Herraiz, 2011
1986	20	Port Landings					González Herraiz, 2011
1985	19	Port Landings					González Herraiz, 2011
1984	12	Port Landings					González Herraiz, 2011
1983	28	Port Landings					González Herraiz, 2011
1982	30	Port Landings					González Herraiz, 2011
1981	26	Port Landings					González Herraiz, 2011
1980	30	Port Landings					González Herraiz, 2011
1979	38	Port Landings					González Herraiz, 2011

Table B.1.2. Number of Trips and Hauls by Onboard Observers in the Porcupine Bank.

Trips by Onboard Observers in FU16 Porcupine		
Year	Number of Trips	Number of Hauls
1993	1	14
1996	1	4
1997	1	10
1998	1	19
1999	2	20
2001	1	5
2004	1	22
2007	2	18
2008	3	68
2009	2	58
2010	3	61
2011	2	41
2012	3	59

Table B.2.1. Biological Input Parameters for FU16 *Nephrops* Stock.

Parameter	Value	Source
Discard Survival	0	Discards considered negligible (ICES, 2012)
MALES		
Growth – K	0.14	based on values in other areas (Anon. 1991)
Growth - L(inf)	75	based on maximum sizes observed in samples
Natural mortality - M	0.2	
Length/weight - a	0.0002	WK*NEPH* 2013
Length/weight - b	3.2736	WK*NEPH* 2013
FEMALES		
Immature Growth		
Growth – K	0.14	
Growth - L(inf)	75	
Natural mortality - M	0.2	
Size at maturity	28,7	WK*NEPH* 2013
Mature Growth		
Growth – K	0.1	Anon.
Growth - L(inf)	60	based on maximum sizes observed in samples
Natural mortality - M	0.2	As for males
Length/weight - a	0.0009	WK*NEPH* 2013
Length/weight - b	2.9131	WK*NEPH* 2013

Table B.4.1. Effort by Country based on VMS at trawling speeds 2006–2011.

Year	ESP	FRA	IRL	OTH	Total
2006	38.3	30.5	35.6	28.9	133.3
2007	48.0	20.1	41.8	26.7	136.7
2008	47.8	4.6	23.2	20.0	95.6
2009	31.1	11.7	15.0	10.8	68.5
2010	17.3	6.0	27.2	6.5	57.0
2011	11.1	8.1	45.3	4.4	68.9

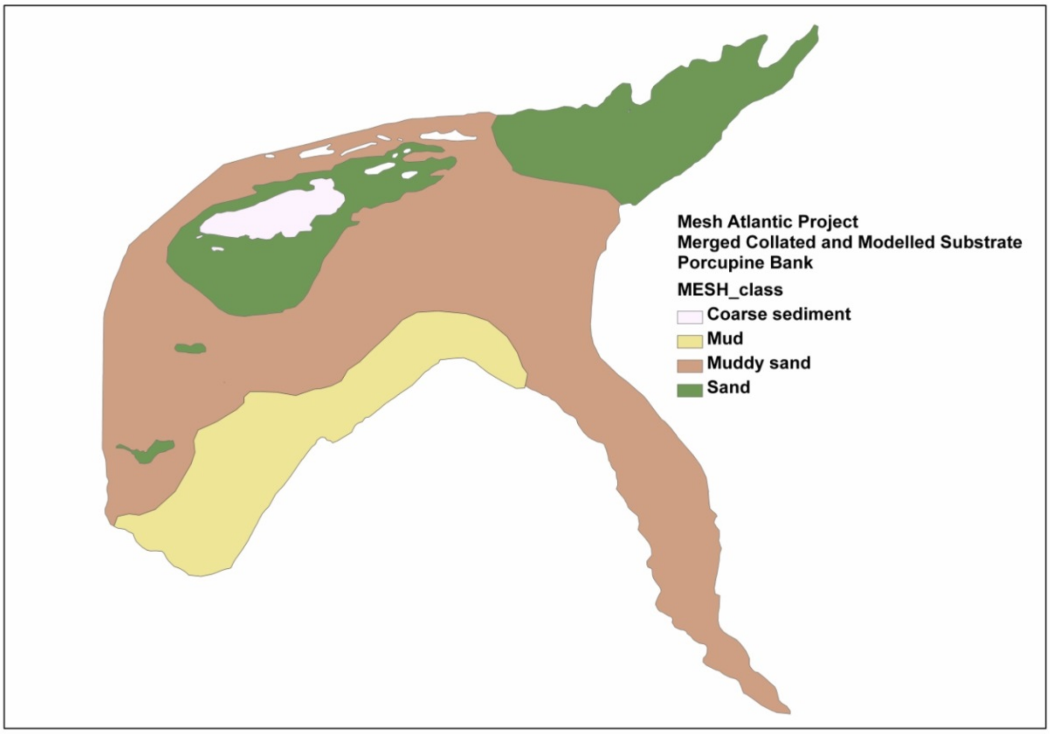

Figure A.3.1. Substrate map of Porcupine Bank depicting the *Nephrops* ground mud patch.

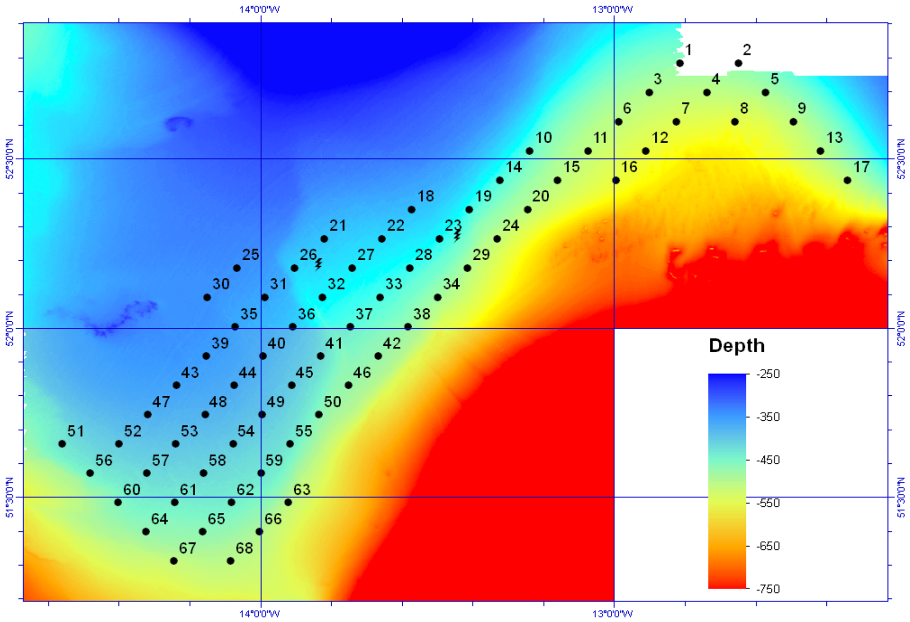

Figure A.3.2. Bathymetry of the Porcupine Bank from seabed mapping surveys and black circles indicate 2012 UWTV survey stations.

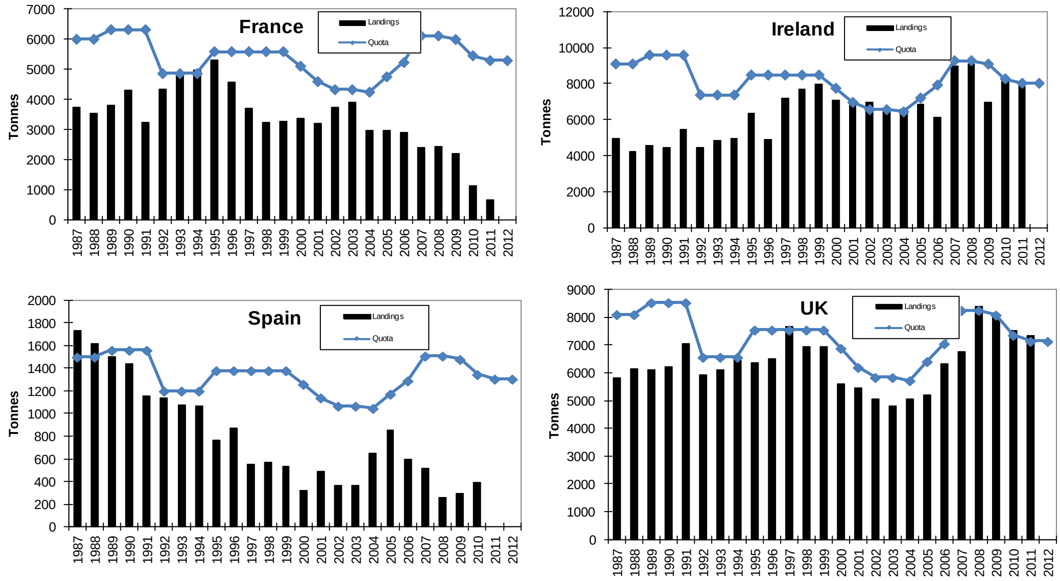

Figure B.1.2. The time-series of landings and quota by country for VII *Nephrops* since the introduction of TACs in 1987. (no Spanish landings were available for 2011).

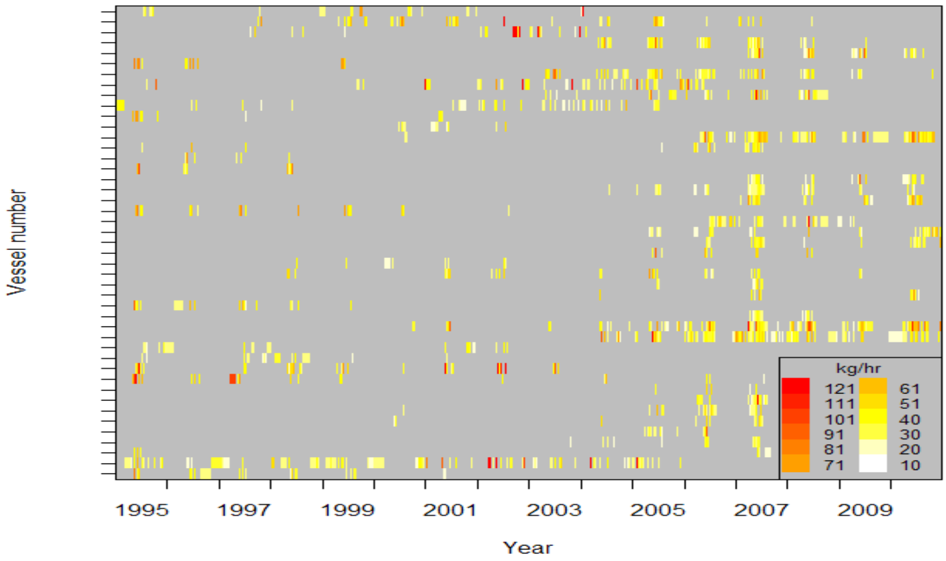

Figure B.4.1. Lpue of Irish *Nephrops* vessels with >1000 hour effort and >30% *Nephrops* in the landings.

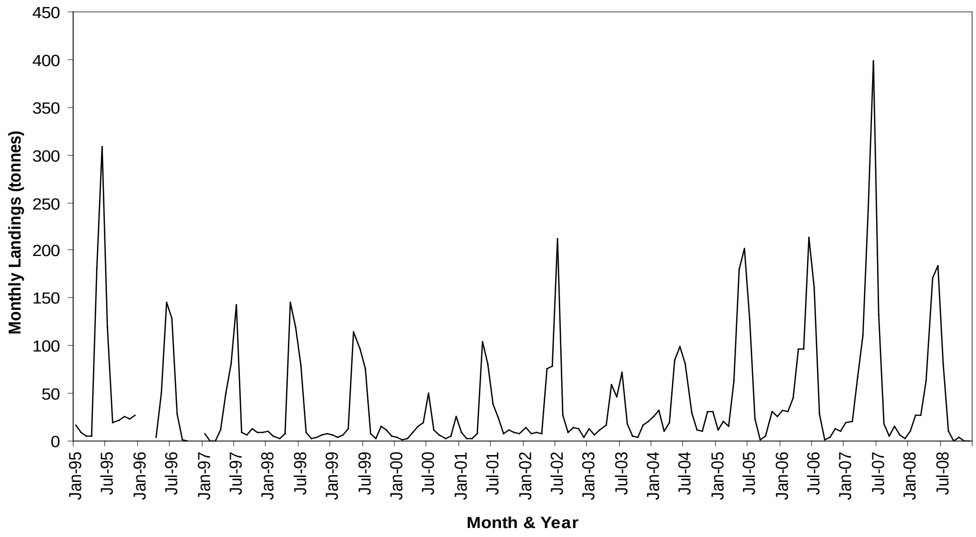

Figure X. Irish monthly *Nephrops* landings between 1995–2008 from the Porcupine Bank (FU16).

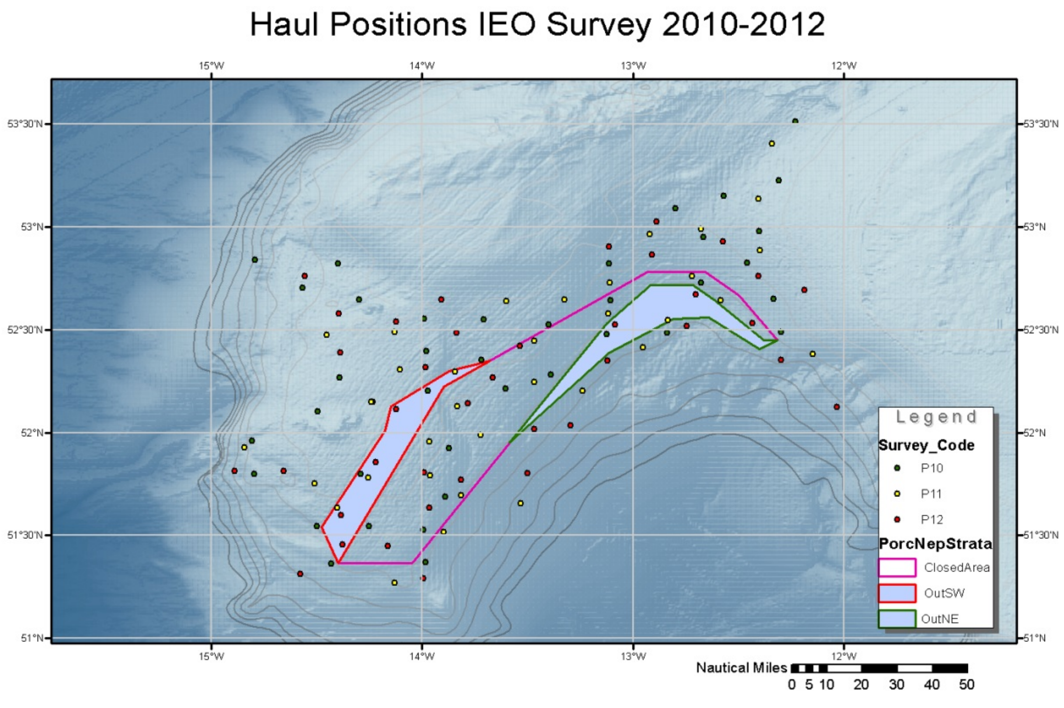

Figure B.3.1. Haul positions of Spanish Groundfish survey series 2010–2012. Closed area (May–July 2010 to 2012) = purple outline and two strata of fishing importance (OutSW and OutNE) are displayed.

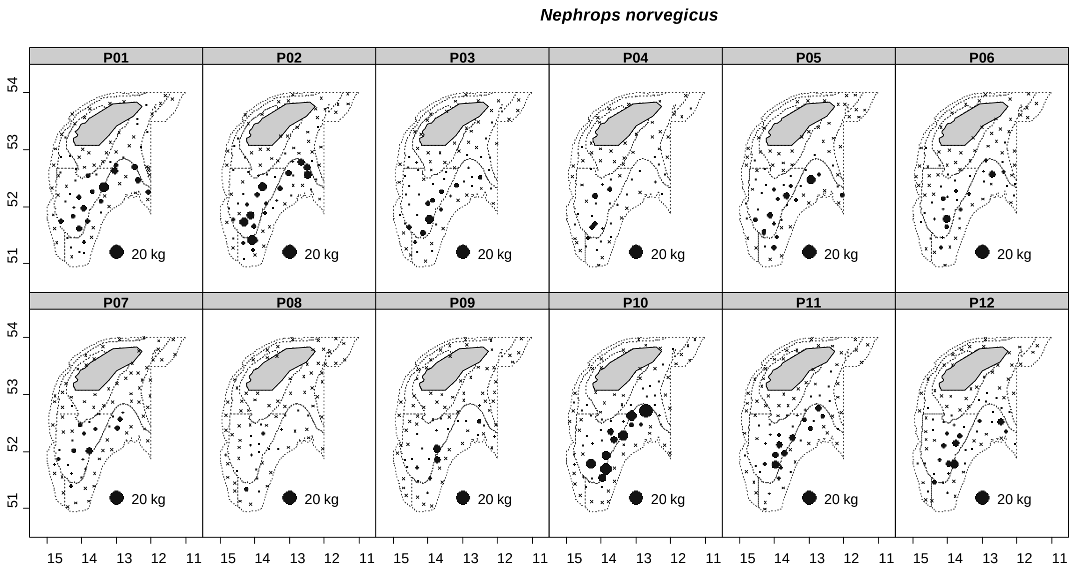

Figure B.3.2. Distribution of *Nephrops norvegicus* catches in Porcupine surveys between 2001 and 2011. The grey polygon is an area of untrawlable seabed.

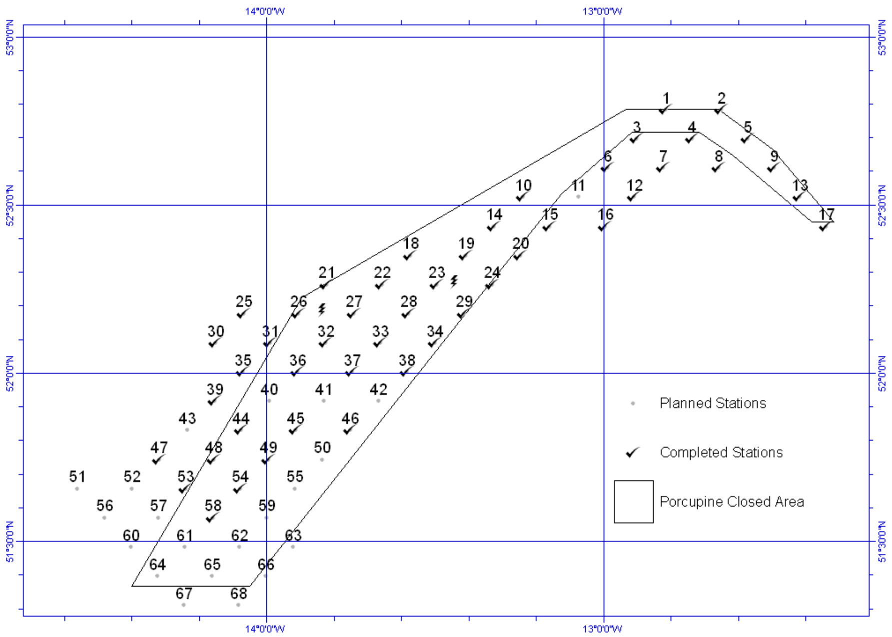

Figure B.3.3. TV stations completed during the UWTV survey of the Porcupine.

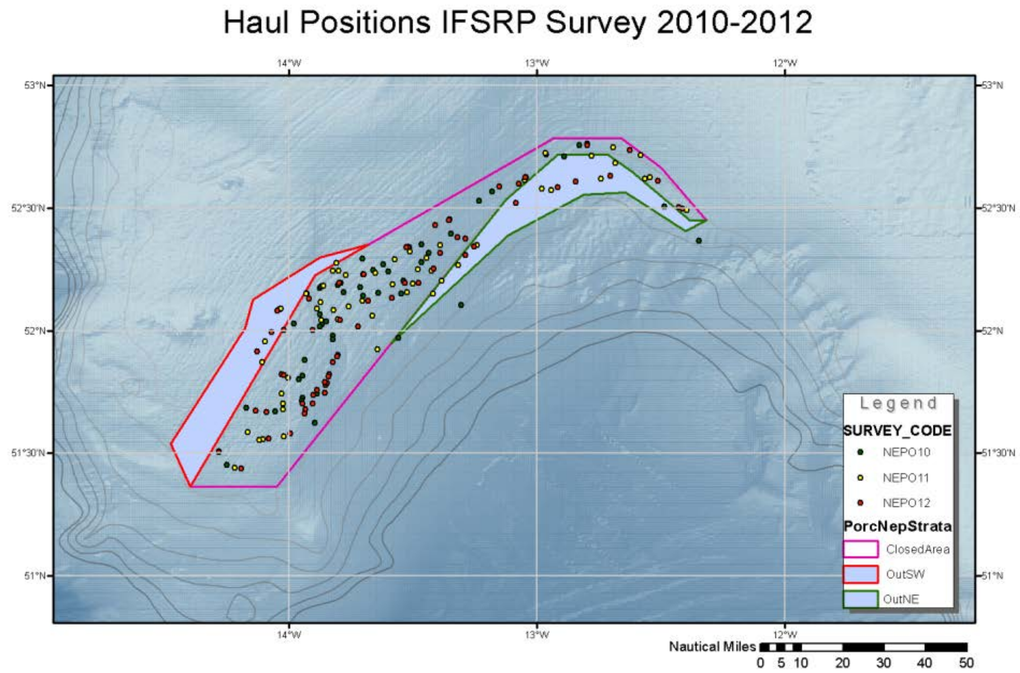

Figure B.3.4. Haul positions of IFSRP survey series 2010–2012. Closed area (May–July 2010 to 2012) = purple outline and two strata of fishing importance (OutSW and OutNE) are displayed.

Stock Annex for FU 34 Devil's Hole

Stock	Devil's Hole *Nephrops* (FU 34)
Working Group	WGNSSK
Date	27 February 2013
Revised by	WK*NEPH*2013/Helen Dobby and Adrian Weetman

A. General

A.1. Stock definition

Nephrops are dependent on particular types of seabed sediment with a preference for fine muddy sediments (silt & clay content of 10–100%) suitable for excavating burrows (Farmer, 1975; Afonso-Dias, 1998). Therefore, there is a close relationship between the distribution of *Nephrops* stocks and sediment type. A British Geological Survey (BGS) map of the North Sea (Figure A.1) shows a number of patches of muddy sand (10–50% silt and clay) in the central North Sea, to the south of the Fladen (total area 4000 km^2). This area is known as the Devil's Hole and consists of a number of narrow trenches, typically 1–2 km wide, running in a north–south direction with an average length of 20–30 km. These trenches fall across seven ICES rectangles: 41–43F0, 41–43F1 and 40F0.

In other areas, the sediment maps have been shown to be inaccurate (Campbell *et al.*, 2009 and Dobby *et al.*, 2013 WD submitted to WK*NEPH*2013) and this has resulted in the spatial extent of *Nephrops* being defined using maps of fishing activity (vessel monitoring system data) instead of sediment data. A comparison of the sediment map and VMS data associated with a landing of at least 30% *Nephrops* by weight (filtered for speeds of <3.8 knots and 70–99 mm mesh) suggests that the spatial extent of *Nephrops* in this area (at least at densities suitable for fishing) is somewhat less than that apparent from the BGS map (Figure A.2).

Estimating the area of the spatial extent of the *Nephrops* habitat from VMS data has been carried out using the alpha convex hull method to identify a polygon encompassing the VMS pings (using the alpha hull library in R, Figure A.3). Mesquita *et al.* (2010) explored the sensitivity of alternative values for the alpha parameters and concluded that a value of alpha=0.01 enclosed the major areas of fishing activity, but excluded those with a low intensity of VMS pings.

While considering the fished area, a number of additional areas of fishing activity were identified to the south of the previously defined area; in statistical rectangles 39F0 and 40F0. These contribute only a small amount in terms of total area and landings (<5% of 41–43F0–F1) and are therefore currently not included in the spatial extent of the stock.

The spatial extent across rectangles 41–43F0–F1 is estimated as 1753 km^2 (based on union of VMS polygons estimated on an annual basis; See WK*NEPH* 2013 report for details).

A.2. Fishery

The fishery in this area is prosecuted largely by Scottish vessels operating out of ports in the northeast of Scotland, but occasionally making landings into northeast England. The fleet consists of large *Nephrops* trawlers which have the capability of operating in such offshore areas. The fishery increased during the mid-2000s (Figure A.4) and at its peak around five vessels operating out of Peterhead and another twelve from Fraserburgh were regularly visiting the areas. These vessels also fish the Fladen on a regular basis and visit the other more inshore functional units in times of poor weather or poor *Nephrops* catch rates in the offshore areas. The fishery is a mixed fishery with vessels typically landing a range of demersal fish species such as cod, haddock and whiting, in addition to *Nephrops*. Although there does not appear to be strong seasonal patterns in the fishery, *Nephrops* landings are generally lowest in quarter 1. Landings by vessels from other nations comprise <5% of the total.

A TAC is set for *Nephrops* in ICES Subarea IIa and IV (EC waters) which in 2012 was set at 21 929 tonnes with an additional allowance of 1200 tonnes in Norwegian waters. The minimum landings size (MLS) for *Nephrops* in Subarea IV (EC) is 25 mm.

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 codline. 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 than 100 mm in the North Sea south of 57˚30'N; check this. Separate Scottish legislation (SSI 405/2000) prohibits the use of more than two nets by any Scottish fishing boat wherever it may be; or by any relevant UK fishing boat within the Scottish zone.

B. Data

B.1. Commercial catch

Landings and effort data from logbooks are available from the Scottish fleet. Other nations supply landings data. As in other *Nephrops* functional units, the reliability of the landings data is likely to have improved since the introduction of UK buyers and sellers legislation in 2006.

The following table shows the nations supplying data for this FU.

Country	Landings weight	Landings length composition	Discards length composition	Length composition in catch
Denmark	X			
Netherlands	X			
UK(E & W)	X			
UK (Scotland)	X	X	X	X

Length compositions of Scottish landings and catch (both landed and discarded components) are obtained during market sampling and on-board observer sampling respectively. In 2011, length–frequency samples of marketable and discarded *Nephrops* have been limited to a single observer trip and sampling was also relatively poor in 2010. Table B.1 shows the number of samples by year.

Within MSS, sampled *Nephrops* landings length frequencies are raised to trip level and then to fleet level. Since 2011, these fleets have been defined according to aggregations of métiers as agreed under the WGNSSK/WGMIXFISH data call and uploaded to InterCatch where the international raised data are calculated.

The recent length–frequency information (Table B.2) is considered of insufficient quality for deriving an exploitation pattern for use in per-recruit analysis. Instead the mean weight in the landings has been calculated over the years 2007–2010 (31.76 g) for use in the *Nephrops* data-limited approach (Table B.3). This should be used until there is evidence to indicate that this has changed such as when adequate data are available.

Data on the landed and discarded component of catches obtained from observer trips have been used to estimate a discard rate. Annual rates have been averaged over 2008–2011 (WK*NEPH* 2013) to provide an estimate of discard rate (12.9%) to be used in the data-limited approach to the provision of advice.

B.2. Biological

Dynamics for this stock are poorly understood and studies to estimate growth have not been carried out. Parameters applied in to inform the catch forecast process were taken as follows: natural mortality was assumed to be 0.3 for males of all ages and in all years (Morizur, 1982). Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females.

The calculations of mean weight make use of the length–weight parameters of Fladen *Nephrops* (FU7). In future, it is likely that the assessment will require other biological parameters (as in the full UWTV survey approach). WK*NEPH* 2013 considered that it would be most appropriate to use those from the Fladen, an offshore geographical neighbouring FU.

Parameter	Value	Source
MALES		
Length/weight - a	0.0003	Howard and Hall (1983)
Length/weight - b	3.25	Howard and Hall (1983)
Growth - L_∞	66 mm	Adapted from Bailey and Chapman (1983)
Growth - k	0.16 yr^{-1}	Adapted from Bailey and Chapman (1983)
Size at maturity	25 mm	Adapted from Bailey (1984)
Natural Mortality - M	0.3	Morizur (1982)
FEMALES		
Length/weight - a	0.00074	Howard and Hall (1983)
Length/weight - b	2.91	Howard and Hall (1983)
Immature growth - L_∞	66 mm	Adapted from Bailey and Chapman (1983)
Immature growth - k	0.16 yr^{-1}	Adapted from Bailey and Chapman (1983)
Immature natural mortality - M	0.3	Morizur (1982)
Size at maturity	25 mm	Adapted from Bailey (1984)
Mature growth - L_∞	56 mm	Adapted from Bailey and Chapman (1983)
Mature growth - k	0.10 yr^{-1}	Adapted from Bailey and Chapman (1983)
Mature natural mortality - M	0.2	Based on Morizur (1982) ; assuming lower rate for mature females

Discard survival

The patchy nature of the ground at the Devil's Hole and the behaviour of the fleet (moving between suitable *Nephrops* patches) may mean that discarded *Nephrops* are not returned to the sea over suitable sediment. In such circumstances, it is assumed that there is no discard survival. This is in line with previous assumptions for the Farn Deeps.

B.3. Surveys

Prior to 2009, UWTV surveys were conducted at the Devil's Hole on an opportunistic basis. Station locations on these early surveys were randomly selected from the BGS sediment map. Since 2009, the survey has used a fixed station design, with station locations chosen from the set of 2008 VMS pings (Figure B.1).

On average, about 15–20 stations have been considered valid each year in the recent period which equates to approximately nine stations per 1000 km^2 (towards the lower end of station densities across surveyed FUs). A range of density estimates covering recent values are raised to a stock area of 1753 km^2 based on the analysis of VMS data to calculate a range of abundances for use in the DL approach. General survey protocols and analysis methods for underwater TV survey data are similar for each of the Scottish surveys and follow guidelines established by SGNEPS (ICES, 2008, 2009). In the recent period, the relative standard error for the Devil's Hole density estimate has fluctuated around the level recommended as adequate by SGNEPS and averaged over 2009–2011 is 0.22 (recommended <0.2).

Relative to absolute conversion factor

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as absolute (required for both the *Nephrops* data-limited approach and the full UWTV survey approach), it is necessary to correct for these potential biases. These are based on simulation studies, preliminary experimentation and expert opinion.

For the Devil's Hole, the footage, in terms of burrow complex diameter appears very similar to those apparent at the Fladen. The edge effect was therefore estimated as 1.45 (from Campbell *et al.*, 2009). Burrow detection rates were believed to be relatively high due to the excellent water clarity and burrow identification was believed to be 100% due to a lack of other burrowing fauna. The cumulative correction factor for the Devil's Hole was calculated as 1.4. This is higher than the correction factor in other FUs.

	Edge effect	detection rate	species identification	occupancy	Cumulative bias
FU34	1.45	0.95	1	1	1.4

B.4. Commercial cpue

Lpue data were available for Scottish *Nephrops* trawls. These data are available from 2000 onwards. The effort and lpue are not standardized and therefore do not account for changes in efficiency, seasonality or other factors that could influence the trend in lpue over time. (Table B.4 and Figure B.2).

C. Assessment: data and method

WK*NEPH* concluded that for the time being, advice should be provided for *Nephrops* in FU34 on the basis of the data limited approach (see below and category 4.1.4 of ICES DLS approach). This can provide an indication of the level of medium-term average F in relation to F_{MSY} (borrowed from neighbouring stocks with similar characteristics) and this may also provide guidance on the level of abundance relative to MSY $B_{trigger}$.

In terms of stock trends, there are currently insufficient length frequency data for use in constructing indicators. There is a commercial LPUE series extending back to 2000 which should be used (with caution) to monitor stock trends.

Input data required: **Recent absolute (bias corrected) density estimate from UWTV survey**

In the range 0.2–0.3 m^{-2} but should account for the most recent estimates if different

Spatial extent

1753 km^2

Landings mean weight

31.76 g (average 2007–2010)

Discard rate in number

12.9 % (average annual rate 2008–2011)

Discard survival

0%

Model and software: see spreadsheet derived at WGNSSK 2012 ('FINAL version of Nep-IV nonTVstocks included in advice.xls'-note that the formula used for the 2012 advice is wrong). Steps in formulating the data-limited table:

1) Use absolute density & spatial extent to derive *Nephrops* abundance for a range of densities (see above);

2) Convert potential landings weight into numbers using landings mean weight for a range of total landings (ten year average, half of ten year average, maximum of time-series);

3) Convert landings numbers into total removals by dividing by (1 – discard rate in number);

4) Divide total removals (from 3) by *Nephrops* abundance (from 1) to obtain a matrix of harvest rates which can be compared to F_{MSY}.

D. Short-term projection

Not relevant; uses *Nephrops* data-limited approach.

E. Medium-term projections

Not relevant; uses *Nephrops* data-limited approach.

F. Long-term projections

Not relevant; uses *Nephrops* data-limited approach.

G. Biological reference points

No reference points have been calculated for this functional unit. The *Nephrops* data-limited approach compares calculated harvest rates to the range of F_{MSY} harvest rates estimated for other North Sea functional units (8–16%)

H. Other issues

H.1. Historical overview of previous assessment methods

The Devil's Hole was designated as a separate FU in 2010. ICES first provided advice for this FU in 2012. Prior to this, the landings were collated as part of the total North Sea *Nephrops* landings 'outside FUs.

In 2012, the advice was provided on the basis of the *Nephrops* data-limited approach using parameter values taken from FU7 with conclusions on stock trends drawn from lpue data. For 2013 onwards, more appropriate parameter values have been derived from data collected from FU34.

Year	Mean weight in landings (g)	Discard rate (%)	Area (km^2)	Correction factor
2012	28 (FU7)	5 (FU 7)	1100	1 (no bias assumed)
2013	31.76 (FU34)	12.9 (FU 34)	1753	1.4

The data-limited approach makes use of average densities from the UWTV survey. A number of changes have been made to survey design as knowledge of the grounds has improved. These are documented below.

DATA	PRE 2009	2009–2012
UWTV survey	Opportunistic surveys with stations randomly positioned according to BGS sediment map	Fixed stations drawn from 2008 Scottish *Nephrops* VMS points

I. References

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Pateiro-Lopez, B., and Rodriguez-Casal, A. 2009. alphahull: Generalization of the convex hull of a sample of points in the plane. R package version 0.2-0. http://CRAN.R-project.org/package=alphahull.

Pateiro-Lopez, B., and Rodriguez-Casal, A. 2010. Generalizing the Convex Hull of a Sample: The R Package alphahull. Journal of Statistical Software, 34 (5): 1–28.

Table B.1. Number of catch and landed samples obtained from Devil's Hole (FU 34) by MSS.

	Date Landed – Year						
Type	2006	2007	2008	2009	2010	2011	Grand Total
Observer samples*			30	3	14	12	59
Market samples	1	5	1	5	1		13

Table B.2. *Nephrops*, Devil's Hole (FU 34): Mean sizes (CL mm) above and below 35 mm of male and female *Nephrops* in Scottish landings, 2006–2011.

Year	Landings			
	< 35 mm CL		> 35 mm CL	
	Males	Females	Males	Females
2006	29.7	29.8	39.7	38.1
2007	30.4	28.7	40.5	39.2
2008	31	30.5	40.3	39.6
2009	31.7	31.1	41.3	40.6
2010	32.2	29.9	39.6	39.4
2011	31.7	30.7	43.7	40.4

Table B.3. *Nephrops*, Devil's Hole (FU34): Mean weight (g) in the landings, 2006–2011.

Year	Male	Female	Overall
2006	27.03	17.53	22.93
2007	31.19	16.94	26.27
2008	36.83	21.82	30.08
2009	46.83	24.01	39.62
2010	38.22	18.94	31.07
2011	63.25	25.47	42.05
Average (2007–2010)			31.76

Table B.4. ***Nephrops*****, Devil's Hole (FU 34): landings, effort (days fishing) and lpue (kg/day) for UK bottom trawlers landing in Scotland and fishing *****Nephrops***** with codend mesh sizes of 70 mm or above, 2000–2011.**

Year	Landings	Effort	lpue
2000	185	3391	54
2001	270	3142	86
2002	343	2022	169
2003	674	2614	258
2004	489	1551	315
2005	379	1545	245
2006	448	1440	311
2007	715	1824	392
2008	937	1673	560
2009	1306	1921	680
2010	730	1465	498
2011	423	1041	406

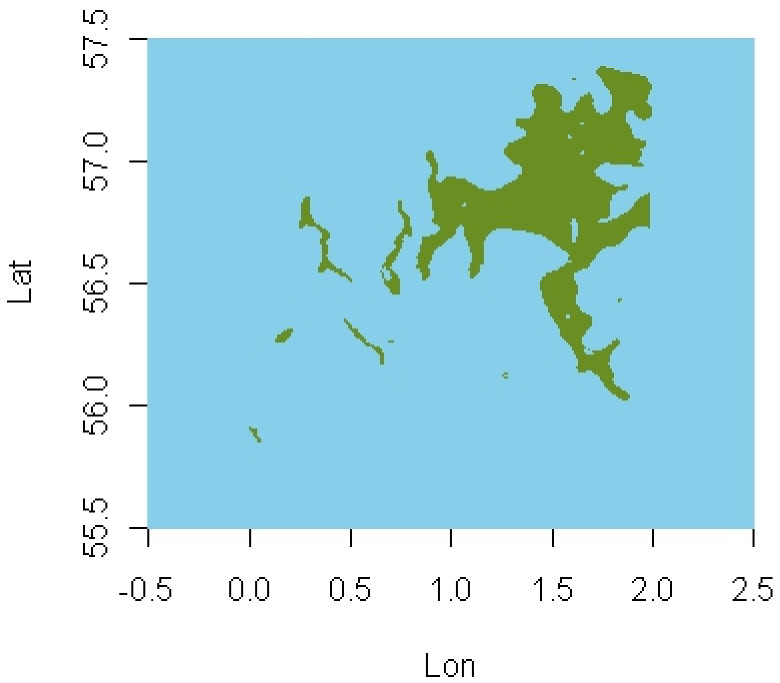


Figure A.1. Distribution of muddy sediment in the central North Sea according to British Geological Survey maps.

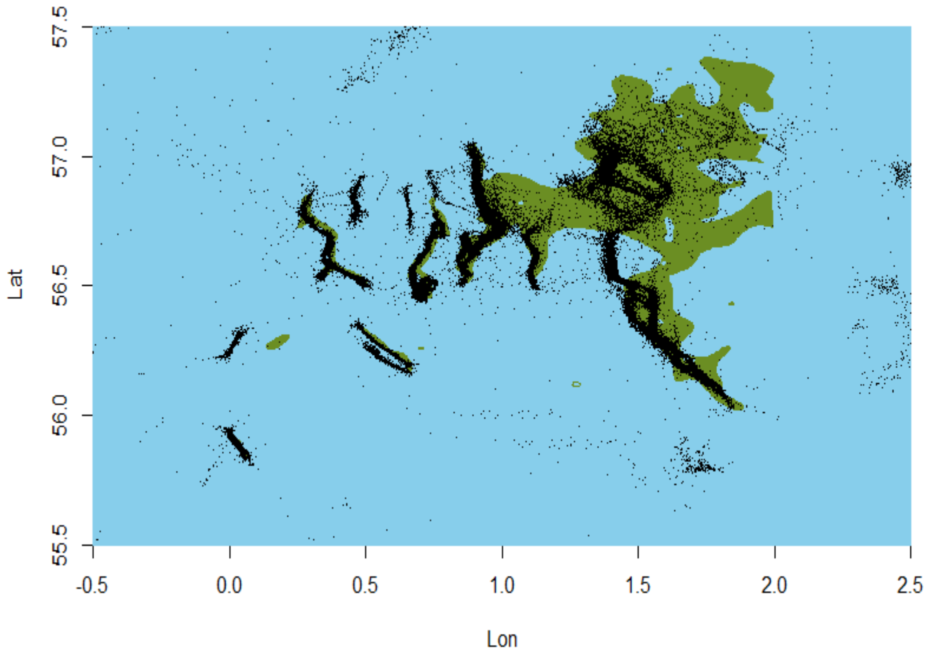


Figure A.2. Comparison of BGS sediment map with VMS data from Scottish trawlers (2007–2011) filtered for landings >30% of total, speeds of 0.5–3.8 knots and mesh size 70–99 mm.

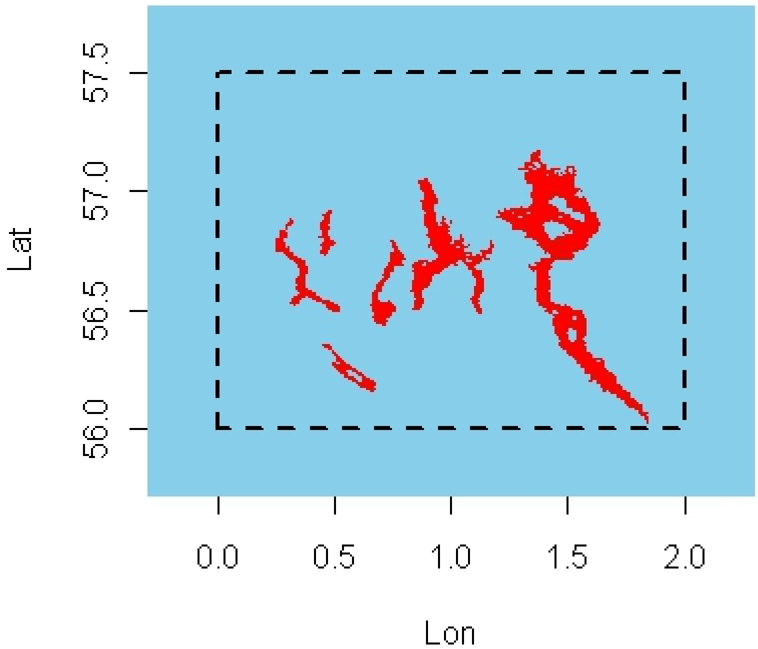


Figure A.3. The area of the spatial extent of the *Nephrops* habitat from VMS data calculated using the alpha-convex hull method.

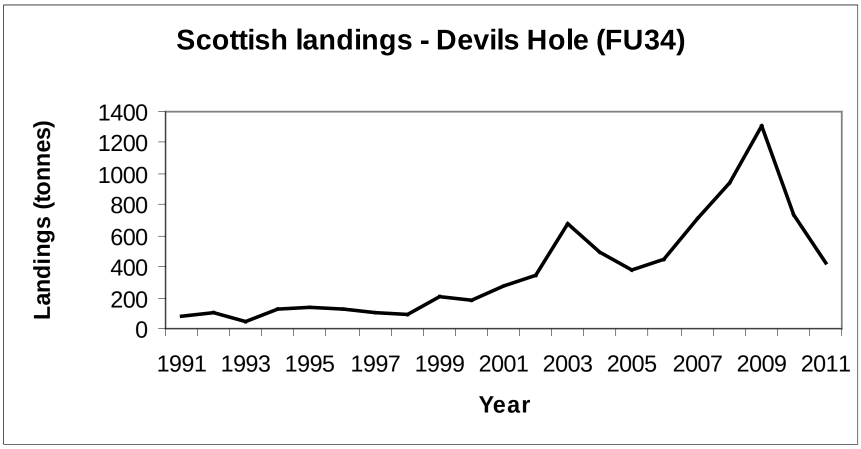


Figure A.4. ***Nephrops*****, Devil's Hole (FU 34). Scottish landings from 1991 to 2011.**

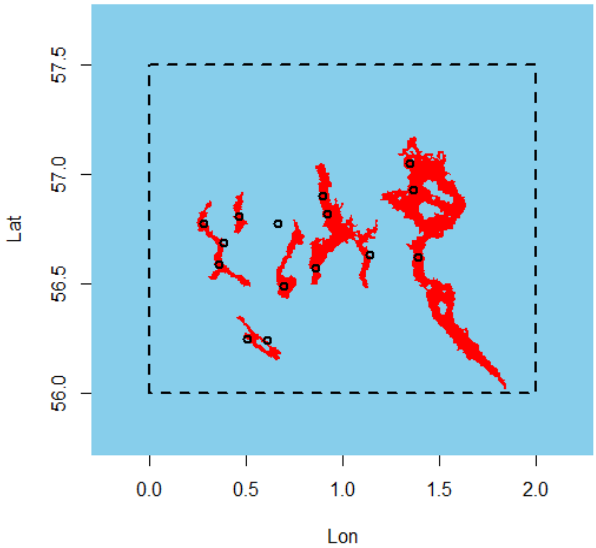
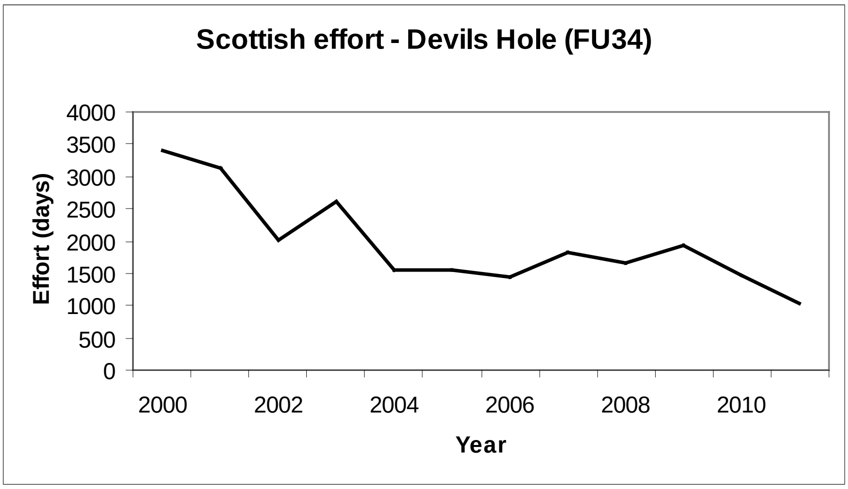


Figure B.1. Fixed UWTV survey station locations (2009 onwards) compared with estimate of spatial extent of *Nephrops* at Devils' Hole.



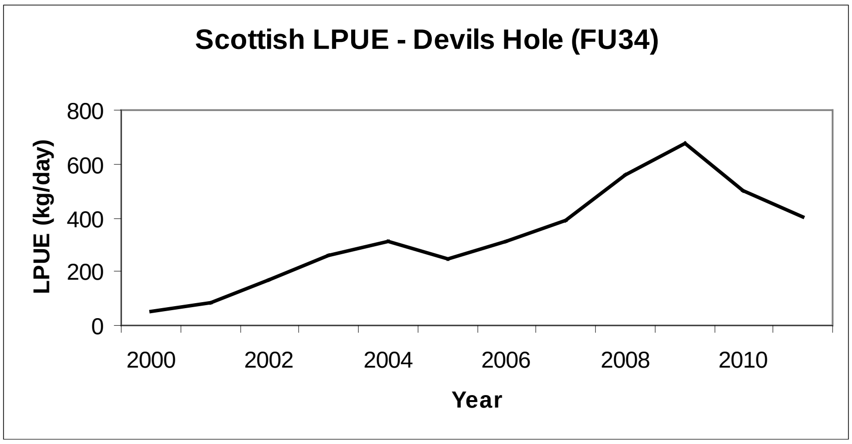


Figure B.2. ***Nephrops*, Devil's Hole (FU 34). Effort (days) and lpue (kg/day by Scottish trawlers).**

Stock Annex for FU 6 Farn Deeps

Stock	Farn Deeps *Nephrops* (FU6)
Working Group	WK*NEPH*2013
Date	March 2013
Revised by	WK*NEPH*2013/Ewen Bell, Ana Leocádio

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt & 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.

The extent of the mud covers the following statistical rectangles:

38–40 E8–E9; 37E9 and the assessed ground is defined by a polygon which encompasses suitable sediment and known fishing tracks (from VMS) as shown in Figure B1.1.0

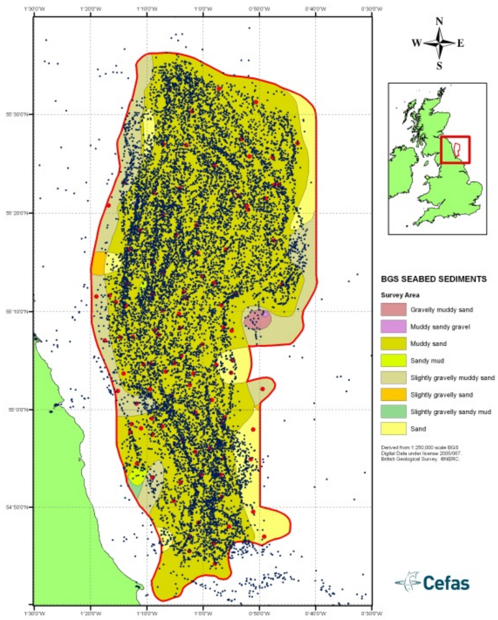


Figure B 1.1.0. Definition of Farn Deeps assessment area.

A.2. Fishery

The *Nephrops* fishery in the Farn Deeps is largely a winter fishery, starting usually in October and extended to March. This fishing pattern has been quite stable over the last 30 years where 80% of the landings occurred in this period. Occasionally, some seasons can shift a bit, having early or later start/endings.

The fleet targeting *Nephrops* in this ground is composed by local vessels (mostly single rigs) and visitors from Scotland (mainly twin rigs), less from Northern Ireland and occasionally form the Netherlands. In the past *Nephrops* was target mainly using single rigs but the proportion of landings from twin trawlers has increased gradually since the 1990s. From 2008 the proportion of landings taken by the twin rigs stabilized, accounting with 40% of the landings.

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.

Fishing by the 'local' vessels is usually limited to a trip duration of one day with two hauls of 3–4 hours being carried out. The larger vessels tend to make trips of between three and seven days with tows of around five hours. The main landing ports are North Shields, Blyth, Amble and Hartlepool where respectively, 50, 29, 11 and 7% of the landings from this fishery are made (average 2003–2012).

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, and then decreasing back to more historical levels. 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. 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. Twin and 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 minimum landing size for *Nephrops* in the Farn Deeps is 25 mm CL. Discarding generally takes place at sea, and in the past it was usually continued alongside the quay. From 2008–2009 there was a big reduction of sorting at the quay side and nowadays this practice is considered sporadic. Landings are usually made by category for whole animals, often split into "large" and "medium" categories with a further category for "tails". However, landings to merchants of one category of unsorted whole and occasionally one of tails is becoming more common.

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 codline. 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. In addition to these conventional gears, due to the cod long-term management plan (Regulation (EC) No 1342/2008), English vessels, over 10 m, landing more than 5% cod, must use a gear that catches less than 1.5% cod for 20 fishing days (can be split ten plus ten consecutive days) when fishing N of 55 (which bisects the Farn Deeps *Nephrops* fishery). Scottish vessels must use a 'Highly Selective Gear' ("selectivity" referring to lower efficiency for finfish rather than size selectivity for *Nephrops*) for the whole fishing year but these gears show no change in their selectivity for *Nephrops*. It is thought that options for Highly Selective Gear may be given to the English fleet to compliment the use of the grid. The differential in technical measures in force across the ground may affect the length composition of catches.

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 than 100 mm in the North Sea south of 57°30'N. Scottish legislation prohibits Scottish vessels from using multiple (>2) rig trawls in all UK waters.

Under the common fisheries policy (CFP) reform the discard ban will became effective for *Nephrops* from 2015.

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, market sampling (landings), on-board observer sampling (discard and retained samples) and the *Nephrops* catch sampling programme which provides monthly samples during the fishing season (typically October–March) covering North Shields, Blyth, Amble and Hartlepool fishing ports. This catch sampling programme provides information on *Nephrops* size distribution, sex ratios, weight–length and maturity.

Years prior to 2002

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.

2002–current

The market sampling data have not been used in the raising process since 2008. There was concern that the ratio between samples of tails and whole animals was not in the same proportion as was coming ashore (tails were underrepresented in the samples). This was thought to be inducing bias in the resulting length frequencies.

On-board discard sampling has been of sufficient frequency since 2002 to allow the estimation of discards from these data. As with the landings sampling, the practice of tailing causes some sampling issues, although with the observer data it is not thought to be an insurmountable problem. Historically there have been are two modes of operation for “tailing” in the FU6 *Nephrops* fishery, some vessels tailing at sea, others tailing at the quayside although quayside tailing has virtually ceased since around 2010. Observer records of "discards" are only made when active discarding practice is observed, hence on occasions where the catch was left to be sorted (and tailed) at the quayside, an observer sample would record all individuals as "retained", although this may contain individuals well below MLS. Figure B.1.1 shows the frequency distribution of discarding practice below MLS and there is a clear spike of 0% discarding. Inclusion of these samples in the discard estimation process would induce significant bias and therefore samples with less than 20% discarding observed below MLS are ignored in subsequent processing.

Annual discard ogives demonstrated no systematic change, therefore a single ogive was constructed from the pooled data from 2002–2010 (Figure B.1.2). This was then applied to the catch data to produce estimates of landings-at-length.

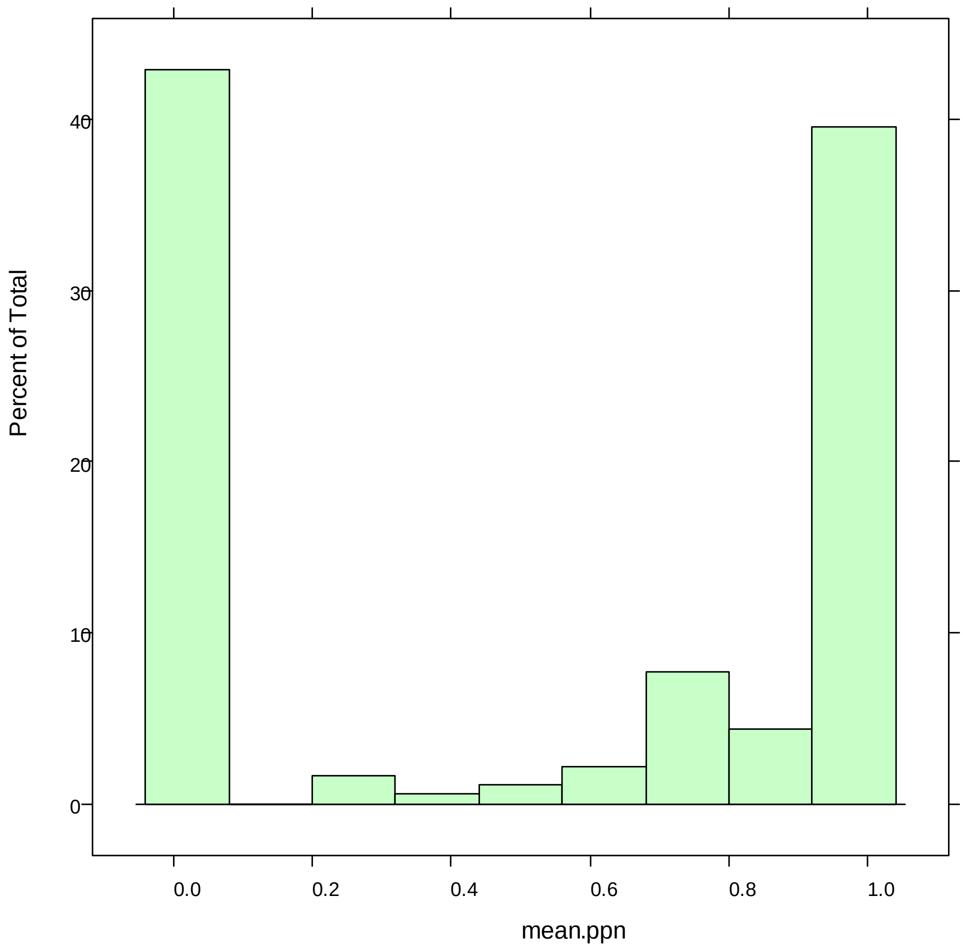


Figure B.1.1. Farn Deeps (FU 6): Histogram of proportion individuals <26 mm discarded.

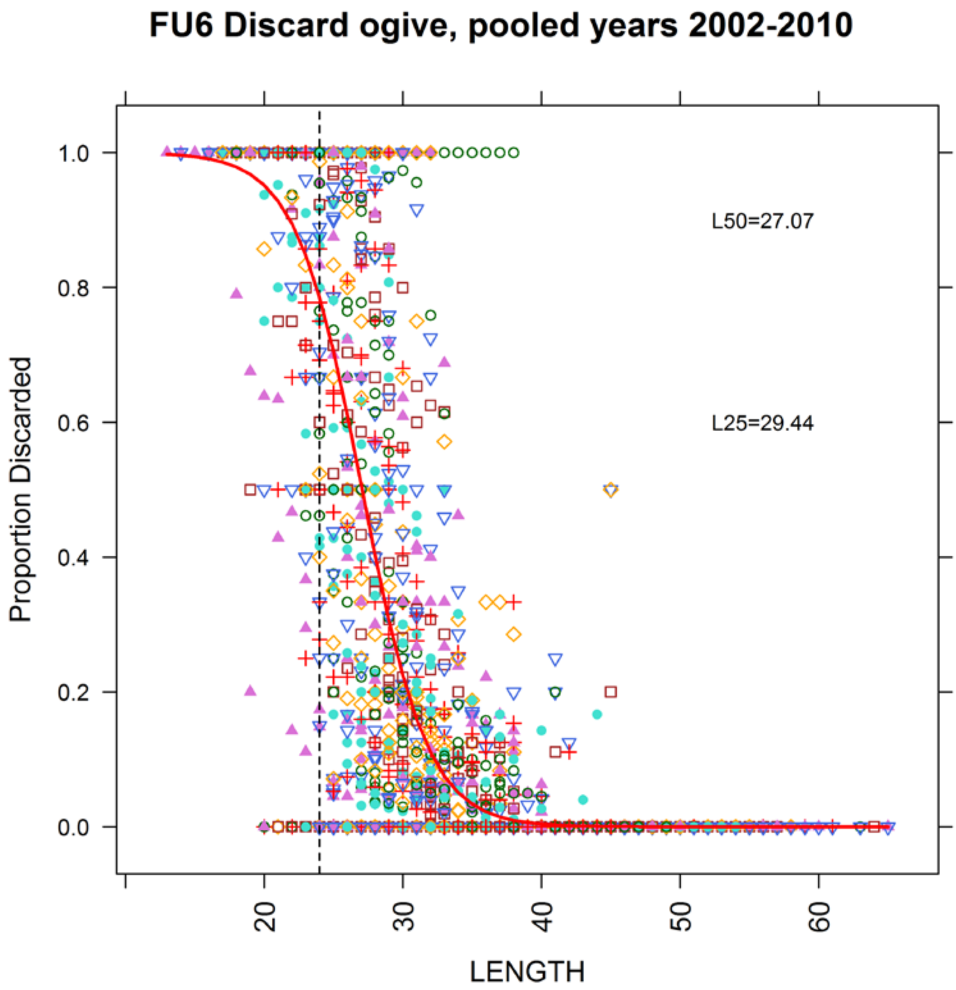


Figure B.1.2. Farn Deeps (FU 6): Discard ogive selected for FU6 *Nephrops*, trip level data spanning 2002–2010.

B.2. Biological

Growth

Growth parameters presented in WK*NEPH* 2009 were estimated by Macer (unpublished data) from observations of the Farn Deeps fishery and comparison with adjacent stocks. No changes were made in these parameters at WK*NEPH* 2013.

Length-weight

Prior to 2011 weights-at-length for this stock were estimated from a fixed weight–length relationship derived from samples collected from this fishery (Macer, unpublished data).

At WK*NEPH* 2013 length–weight data were reviewed. These data have been collected monthly during the *Nephrops* catch sampling programme (during the fishing season) since 1984. Length–weight relationships have been reasonable stable during the time-series and so the updated parameters presented in WK*NEPH* 2013 were calculated from the pooled data 2010–2012 for both males and females.

Maturity

	Female			Male	
	Function	L25	L50	Function	L50
2004	Knife-edge		24.0	Knife-edge	26.7
2006	Knife-edge		24.8	Knife-edge	25.8
2009	Sigmoid	24.5	25.0	Knife-edge	29.8
2013	Sigmoid	27.2	30.5	Knife-edge	25.2

The size-at-maturity for females was recalculated at ICES WK*NEPH* 2006 to be 24.8 mm CL. 24 mm CL was used in assessments prior to 2009. The sigmoid maturity function used at WK*NEPH* 2009 estimate L25 = 24.5 mm and L50 = 25 mm.

At WK*NEPH* 2013 maturity data available from the *Nephrops* catch sampling programme was review and estimates of the L50 were obtained for females since 1985 (visual examination of the ovaries and/or egg bearing condition, using Symmonds stages up to 2004 and using Redant stages from September 2004 onwards, Table 2). Maturity stages were harmonized to compare the entire dataset.

Natural mortality

A natural mortality rate of 0.3 was assumed for males (Morizur, 1982) 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. No changes in these parameters were made at WK*NEPH* 2013.

Nephrops discard survival

Year	Survival
<1991	25%
1991	0%
2013	15%

Before 1991, *Nephrops* discard survival was assumed to be 25%, however in 1991 it was set to zero on the basis that most sorting occurred whilst the vessel was steaming back to port and the discarded prawns would be likely to fall on unsuitable ground.

The discard survival was reviewed in 2013 on the basis that the discarding practice changed since 2008–2009, from where local vessels started to sort most of the catch while at sea, discarding at suitable *Nephrops* grounds. As well the increase of big vessels in this ground, which can spend several days at sea, also increased the discarding of *Nephrops* in suitable grounds. Additionally, due to the nature of this winter fishery, the temperature shock can be considered low and so favour the survival rate. Based on these facts the survival rate was updated to 15% although it has minimal effect upon the MSY proxies.

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,

Maturity parameters

Size-at-maturity females (pool data 2010–2012, catch sampling programme):

L25=27.16 (SE: 0.333) mm, L50=30.48 (SE: 0.261) mm.

Weight–length parameters (pool data 2010–2012, catch sampling programme)**:**

Males a = 0.00048, b = 3.112 (Residual SE: 0.1361; Multiple R-squared: 0.9628)

Females a= 0.00111, b = 2.850 (Residual SE: 0.09819; Multiple R-squared: 0.9795)

Discards

Discard survival rate: 15%

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 showed 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 shown 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 and then summed to give the new total.

The procedure was revised again in 2011 and a geostatistical approach was taken, working the survey data back to 2007 in order to completely remove the bias between station density and burrow density. The procedure is run using the R statistical package with the gstat, maptools, and spatstat libraries.

A boundary file was created using the VMS and BGS sediment data on the MapInfo GIS system and is used to delimit the boundaries of the kriged map.

Mean density per station and the geographical coordinates (transformed from latitude and longitude into metres displacement from 54.67275 N, -1.332769 E) are first fitted with a variogram model. The following commands are used to fit the variogram (the data are held in dataframe “recounts7”).

```
gstat.recount  <-  gstat(id="BurrowDensity",formula=BurrowDensity~1,  loca-
tions=~lon.m+lat.m, data=recounts7)
vario.recount  <-  variogram(BurrowDensity~1  ,  locations=~lon.m+lat.m,  da-
ta=recounts7)
fit.vario.recount <- fit.variogram(vario.recount, model=vgm(0.1, "Exp", 15000,
0.03))
plot(vario.recount, fit.vario.recount)
```

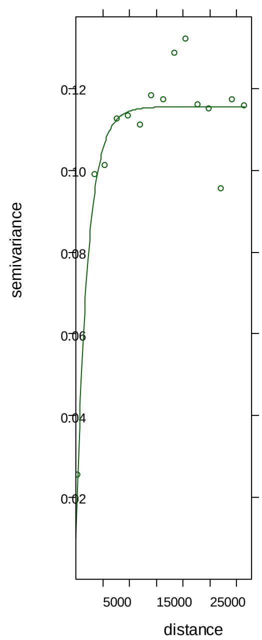


Figure 1.

A kriged estimate of density is then produced for a 500*500 m grid of points lying inside the boundary with the following code.

```
coordinates(recounts7)=~lon.m+lat.m

#and the grid we're going to produce
pred.lat <- seq(from=y.range[1], to=y.range[2], by=500)
pred.lon <- seq(from=x.range[1], to=x.range[2], by=500)

recount.grid  <-  data.frame(lat.m=rep(pred.lat,  each=length(pred.lon)),
lon.m=rep(pred.lon, times=length(pred.lat)))
pos  <-  point.in.polygon(recount.grid$lon.m,  recount.grid$lat.m,  bounda-
ry$dist.lon, boundary$dist.lat)
recount.grid <- recount.grid[pos>0,]
gridded(recount.grid)=~lon.m+lat.m

coordinates(boundary)=~dist.lon+dist.lat

#krig it
krige.recount  <-  krige(BurrowDensity~1,  recounts7,  recount.grid,  mod-
el=fit.vario.recount)
res <- (sum(krige.recount$var1.pred*250000)/1000000) /bias

# each cell represents a 500m*500m block = 250000 sq m, divide by 1million to
get the index in millions
```

By bootstrapping the recount data with replacement it is possible to estimate the uncertainty on the survey abundance estimate. Typically this comes out at a ~2% confidence interval.

UWTV relative to absolute conversion factors

A number of factors are suspected to influence the ability of the surveys to map directly to absolute abundance.

Time period	Edge effect	detection rate	species identification	occupancy	Cumulative Absolute Conversion Factor
<=2009	1.3	0.85	1.05	1	1.2

B.4. Commercial cpue

Catch-per-unit-of-effort time-series are derived from the recorded effort for English vessels using gears 7, 13, 14, 15 and 96 (unspecified otter, *Nephrops*, twin-*Nephrops*, triple *Nephrops* and quad-*Nephrops* gears), using mesh in the range of 70–99 mm is used in conjunction with their reported landings.

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.

Advice Generation Protocol

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

2) Apply the Absolute Conversion Factor (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 an average taken over an appropriate time-scale. 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 $F_{0.1}$, $F_{35\%SpR}$ and F_{MAX}. These values are estimated by Benchmark Workshops (ICES, 2013) but may be revised if there indications of changes to fishery or biological factors.

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) Create a landings number by applying the discard ratio.

8) Produce landings biomass by applying mean weight.

Biological reference points

Harvest ratios equating to fishing at $F_{0.1}$, $F_{35\%}$ spawner per recruit and F_{MAX} were calculated in WK*NEPH* (2009) and subsequently revised by WGNSSK 2011 and WKNephBench 2013. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm (ICES 2009, 2013 Section 3) and that the supplied length frequencies represented the population in equilibrium.

Harvest ratios were reviewed in 2013 with the new updated parameters. The value used for the F_{MSY} proxy is $F_{35\%}$ males. The rationale behind this is that the fishery is traditionally strongly skewed towards males, which causes the SpR of males to fall below 25% when the "default" $F_{35\%}$ combined target is used.

The software used to determine the reference points is the Separable Cohort Analysis model as described in Annex 5 of the 2009 *Nephrops* benchmark meeting.

2013 values

		F_{BAR} 20–40 mm		Harvest Rate	% Virgin Spawner per Recruit	
		Female	Male		Female	Male
$F_{0.1}$	Comb	0.09	0.18	9%	47.52%	32.11%
$F_{0.1}$	Female	0.16	0.33	14%	32.63%	18.26%
$F_{0.1}$	Male	0.07	0.14	7%	53.02%	38.50%
$F_{35\%}$	Comb	0.12	0.24	11%	39.98%	24.50%
$F_{35\%}$	Female	0.17	0.37	15%	34.82%	16.64%
$F_{35\%}$	Male	0.16	0.08	8%	57.17%	34.88%
F_{MAX}	Comb	0.17	0.37	15%	34.58%	16.48%
F_{MAX}	Female	0.29	0.61	22%	22.22%	9.47%
F_{MAX}	Male	0.12	0.26	12%	44.70%	23.73%

2011 values

		F_{BAR} 20–40 mm		Harvest Rate	% Virgin Spawner per Recruit	
		Female	Male		Female	Male
$F_{0.1}$	Comb	0.05	0.16	7.21%	67.46%	36.61%
$F_{0.1}$	Female	0.11	0.34	12.68%	48.97%	20.18%
$F_{0.1}$	Male	0.05	0.14	6.38%	70.80%	40.61%
$F_{35\%}$	Comb	0.10	0.30	11.46%	52.56%	22.75%
$F_{35\%}$	Female	0.21	0.62	18.74%	34.84%	12.13%
$F_{35\%}$	Male	0.06	0.18	8.00%	64.42%	33.29%
F_{MAX}	Comb	0.11	0.32	12.08%	50.70%	21.39%
F_{MAX}	Female	0.23	0.69	20.02%	32.51%	11.06%
F_{MAX}	Male	0.08	0.23	9.47%	59.08%	28.12%

2009 values for comparison

		F_{BAR} 20–40 MM		HARVEST RATE	% VIRGIN SPAWNER PER RECRUIT	
		Female	Male		Female	Male
$F_{0.1}$	Comb	0.06	0.17	8.20%	63.00%	38.60%
$F_{0.1}$	Female	0.12	0.33	14.20%	45.60%	22.20%
$F_{0.1}$	Male	0.05	0.15	7.10%	67.10%	43.50%
$F_{35\%}$	Comb	0.11	0.3	12.90%	48.90%	24.80%
$F_{35\%}$	Female	0.18	0.5	19.40%	35.00%	14.80%
$F_{35\%}$	Male	0.07	0.2	9.30%	59.50%	34.80%
F_{MAX}	Comb	0.11	0.3	13.20%	48.30%	24.30%
F_{MAX}	Female	0.19	0.51	19.90%	34.30%	14.40%
F_{MAX}	Male	0.09	0.24	10.90%	54.60%	29.90%

$B_{trigger}$ definition

The TV abundance estimate for 2007, the first year of low stock abundance and concern over recruitment is used as MSY $B_{trigger}$. Using the geostatistical method of estimating abundance this equates to an abundance of 802 million individuals over 17 mm carapace length.

References

Morizur, Y. 1982. Estimation de la mortalité pour quelques stocks de langoustine, *Nephrops norvegicus*. ICES CM 1982/K:10.

Stock Annex for FU 11 North Minch

Stock	North Minch *Nephrops* (FU 11)
Working Group	WGCSE
Date	01/04/2013
Revised by	WK*NEPH*2013/Carlos Mesquita

A. General

A.1. Stock definition

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 and the boundary with the South Minch FU is at 57°30'N. The North Minch FU is characterized by numerous islands of varying size and sea lochs occur along the mainland coast and exhibits the patchiest ground amongst west coast FUs. Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt & clay content of between 10–100% to excavate its burrows. This means that the distribution of suitable sediment defines the species distribution. The sediment data from the British Geological survey is considered incomplete in this FU, therefore the area of the ground is given by the VMS distribution of fishing effort (vessels >15 meters). Results from recent work on mapping the spatial extent of *Nephrops* habitat in the North Minch sea lochs indicate that the muddy habitat is only a very small proportion of the total *Nephrops* grounds (see Section 5.3.2). The total area of the ground is estimated to be 2908 km^2 (Figure B1–4). The North Minch is part of Division VIa and the fishery data for this Functional Unit include the following statistical rectangles: 44–46 E3-E4 (Figure B1–3).

A.2. Fishery

The North Minch *Nephrops* fishery is predominantly exploited by *Nephrops* trawlers using single-rig gear with an 80 mm mesh, although about 20% of landings are currently made by creel vessels. Landings for this FU are only reported from Scotland.

The fleet is mainly formed by smaller trawlers working 1–4 day trips from the main ports of Lochinver, Ullapool, Stornoway and Gairloch. The largest part of the North Minch fleets continued to be based at Stornoway, made up of mostly 15 m length vessels, both single-rigged and twin-rigged trawlers. The Barra fleet is more nomadic as the fishing grounds are more exposed which forces the fleet to find shelter on the east side of the North Minch. The Barra vessels are generally bigger than the Stornoway fleet, being all over 15 m in length.

The minimum landing size for *Nephrops* in the North Minch is 20 mm CL, and less than 1% 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 additional measures 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. For 2012, this regulation effectively limits vessels targeting *Nephrops* with 80–99 mm mesh size to 200 days at sea per year. Additional Scottish legislation (SSI No 2000/226) applies to twin trawlers operating north of 56°N. 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 80–89 mm mesh with a lifting bag and 120 meshes round the codend but with 4 mm single twine. From 2009 onwards under the west coast emergency measures a square meshed panel of 120 mm was also required (Council Reg. (EU) 43/2009).

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. Rates of discarding by length class are estimated for Scottish fleets by onboard sampling. 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 to removals. The discard survival rate for creel caught *Nephrops* have been shown to be high and a value of 100% is used. Removals are raised separately for each sex.

Reported effort by all Scottish trawlers has shown a decreasing trend since 2000 (Figure B1-1). The increase in lpue in 2005 is probably reflecting the increase in reported landings rather than a change in stock abundance. In general, males make the largest contribution to the landings (Figure B1-2). This is likely to be due to the varying seasonal pattern in the fishery and associated relative catchability (due to different burrow emergence behaviour) of male and female *Nephrops*. This occurs because males are available throughout the year and the fishery is also prosecuted in all quarters. Females on the other hand are mainly taken in summer when they emerge after egg hatching. The mean size of smaller animals (<35 mm) in the catch (and landings) is also relatively stable through time (Figure B1-1). 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 (unpublished data). The size at maturity was estimated by Queirós *et al*. (2013). Relevant biological parameters are as follows: natural mortality was assumed to be 0.3 for males (Morizur, 1982) 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

Parameter	Value	Source
Discard Survival (trawl)	25%	Charuau *et al*., 1982; Sangster *et al*., 1997; Wileman *et al*., 1999
Discard Survival (creel)	100%	Wileman *et al*., 1999; Harris and Ulmestrand (2004); Chapman, 1981
MALES		
Growth – K	0.16	Adapted from Bailey and Chapman (1983)
Growth - L(inf)	70 mm	Adapted from Bailey and Chapman (1983)
Natural mortality - M	0.3	Morizur, 1982
Length/weight - a	0.00028	Howard and Hall (1983)
Length/weight - b	3.24	Howard and Hall (1983)
Size at maturity	27 mm	Adapted from Bailey and Chapman (1983)
FEMALES		
Immature Growth		
Growth – K	0.16	Adapted from Bailey and Chapman (1983)
Growth - L(inf)	70 mm	Adapted from Bailey and Chapman (1983)
Natural mortality - M	0.3	As for males
Size at maturity	22 mm	Queirós *et al*. (2013)
Mature Growth		
Growth – K	0.06	Adapted from Bailey and Chapman (1983)
Growth - L(inf)	60 mm	Adapted from Bailey and Chapman (1983)
Natural mortality - M	0.2	
Length/weight - a	0.00074	Howard and Hall (1983)
Length/weight - b	2.91	Howard and Hall (1983)

Discard survival

A discard survival of 25% is assumed for the trawl fleet (Charuau *et al*., 1982; Sangster *et al*., 1997; Wileman *et al*., 1999). The discard survival rate for creel caught *Nephrops* have been shown to be high (see Section 5.2.1.2) and a value of 100% is used.

B.3. Surveys

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

Underwater TV survey (UWTV FU 11): years 1994–present. The survey usually occurs in May/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 methods used in the survey were similar to those employed for UWTV surveys of *Nephrops* stocks around Scotland and are documented by WKNEPHTV (ICES, 2007) and SGNEPS (ICES, 2010; ICES, 2012). In the assessment, burrow densities are raised to the total estimated area. The survey provides a total abundance estimate, and is not age or length structured. Samples are distributed randomly over the area of suitable sediment. The area calculation was based on the alpha convex-hull method to define and characterize the overall shape of a set of points and is described in ICES (2010). A number of annual polygons based on the VMS distribution of effort (2007-2011) was generated and the union of these used to define the area of *Nephrops* ground in the North Minch. The

VMS area was updated in 2013 at the WK*NEPH*2013 and estimated to be 2908 km^2 (Section 5.3.1).

UWTV relative to absolute conversion factors

A number of factors are suspected to influence the ability of the surveys to map directly to absolute abundance. 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 given in the following table and is based on simulation models, preliminary experimentation and expert opinion (ICES, 2009). The biases associated with the estimates of *Nephrops* abundance in the North Minch are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative absolute conversion factor
FU 11: North Minch	2009–2012	1.38	0.85	1.1	1	1.33

B.4. Commercial cpue

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

Scottish trawl gears: Landings and effort data for Scottish trawl gears are used to generate a non-standardized lpue index. Lpue is estimated using officially recorded effort (days absent from port). Effort data are available for the trawl fleet from 2000. There is no account taken of any technological creep in the fleet. Effort data for the creel fleet are not available.

B.5. Other relevant data

C. Assessment: data and method

Model used: UWTV Based Approach to generate catch options

In 2009 WK*NEPH* debated the use of the surveys as either an absolute measure of abundance or a relative index (ICES, 2009). Ultimately this led to a consensus that bias corrected survey abundance estimates could be used directly in the formulation of catch advice. Two modelling approaches were used to estimate sustainable stock specific Harvest Ratio reference points; SCA (a separable LCA model Bell) and Age Structured Simulation model (Dobby) (ICES, 2009).

Software used: Age Structured Simulation model per recruit analysis in R

1) Survey indices are worked up annually resulting in the TV index.
2) Apply the Absolute Conversion Factor (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 an average taken over an appropriate time-scale. 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 $F_{0.1}$, $F_{35\%SpR}$ and F_{MAX}. These values are estimated by Benchmark

Workshops (Section 5.5) but may be revised if there are indications of changes to fisheries or biological factors.

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) Create a landings number by applying the discard ratio (dead discard rate).

8) Produce landings biomass by applying mean weight.

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Under the ICES MSY framework, exploitation rates which are likely to generate high long-term yield (and low probability of overfishing) have been evaluated and proposed for each *Nephrops* functional unit. Owing to the way *Nephrops* are assessed, it is not possible to estimate F_{MSY} directly and hence proxies for F_{MSY} have been determined. Three stock-specific candidates for F_{MSY} ($F_{0.1}$, $F_{35\%SPR}$, and F_{MAX}) were derived from a length-based per recruit analysis (these may be modified following further data exploration and analysis).

There may be strong differences in relative exploitation rates between the sexes in many stocks. To account for this, values for each of the candidates have been determined individually for males, females, and the two sexes combined. The combined sex F_{MSY} proxy should be considered appropriate, provided that the resulting percentage of virgin spawner-per-recruit for males or females does not fall below 20%. If this happens a more conservative sex-specific F_{MSY} proxy should be picked instead of the combined proxy.

In the North Minch the absolute density observed on the UWTV survey is medium (~0.59 burrow/m^2). Historical harvest ratios in this FU have been above that equivalent to fishing at F_{MAX} and landings have been relatively stable in the last thirty years. $F_{35\%SpR}$ (combined between sexes) is expected to deliver high long-term yield with a low probability of recruitment overfishing and therefore is chosen as a proxy for F_{MSY}. 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. The MSY $B_{trigger}$ proposed for North Minch was based on the lowest observed UWTV abundance time-series.

The F_{MSY} proxy harvest rate values were updated at WK*NEPH*2013 from the per-recruit analysis based on input parameters from a combined sex length cohort analysis of 2009–2011 catch-at-length data. All F_{MSY} proxy harvest rate and MSY $B_{trigger}$ values remain preliminary and may be modified following further data exploration and analysis.

Harvest ratio reference points

	MALE	FEMALE	COMBINED
F_{max}	11.1	23.0	13.2
$F_{0.1}$	6.9	12.8	7.7
$F_{35\%SpR}$	8.2	19.6	10.9

	TYPE	VALUE	TECHNICAL BASIS
MSY	MSY $B_{trigger}$	541 million individuals	Bias-adjusted lowest observed UWTV survey estimate of abundance (corrected for the new VMS area estimate)
Approach	F_{MSY}	10.9% harvest rate	Equivalent to $F_{35\%SpR}$ combined sex. F_{MSY} proxy based on length based Y/R.

H. Other issues

H.1. Historical overview of previous assessment methods

Up to 2010 the ground area for the North Minch was based on the British Geological Survey (BGS) and estimated as 1775 km^2. Marine Scotland Science recent access to Vessel Monitoring System data (VMS) has shown that fishing effort for trawlers (length >15 m) clearly extends outside the BGS area for FU 11, which would imply an underestimate of the stock area. In the 2011 and 2012 assessments, a preliminary VMS based area estimated as 2506 km^2 was used for raising abundances. A correction ratio calculated as 1.41 (VMS area / Sediment area) was applied to the previous sediment abundances estimates to get a rough measure of the abundance raised to the VMS area. As more VMS data became available since 2010, in 2013 at the WK*NEPH*2013 the sediment area of North Minch was updated to 2908 km^2. This was based on the union of annual polygons produced from the VMS data which was shown to be the best method to define the ground area in FU 11 as it includes the main fishing areas while it excludes some low intensity areas. The correction ratios to be applied to the previous abundance estimates are now 1.64 (new VMS area / Sediment area) for years 1994–2010 and 1.16 (new VMS area / preliminary VMS area,) for years 2011–2012.

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Table B1-1. *Nephrops*, North Minch (FU11). Nominal Landings of *Nephrops*, 1981–2011.

Year	UK Scotland		
	Trawl landings	Creel	Total**
1981	2490	371	2861
1982	2428	371	2799
1983	2879	317	3196
1984	3610	534	4144
1985	3353	708	4061
1986	2845	537	3382
1987	3601	482	4083
1988	3598	437	4035
1989	2715	490	3205
1990	2075	469	2544
1991	2353	439	2792
1992	3128	432	3560
1993	2784	408	3192
1994	3162	454	3616
1995	3124	532	3656
1996	2502	369	2871
1997	2655	391	3046
1998	2090	351	2441
1999	2847	410	3257
2000	2723	523	3246
2001	2692	567	3259
2002	2854	586	3440
2003	2651	617	3268
2004	2425	710	3135
2005	2285	699	2984
2006	3463	697	4160
2007	3378	590	3968
2008	3242	557	3799
2009	2884	613	3497
2010	1723	540	2263
2011*	2126	570	2696

*** provisional na = not available.**

**** There are no landings by other countries from this FU.**

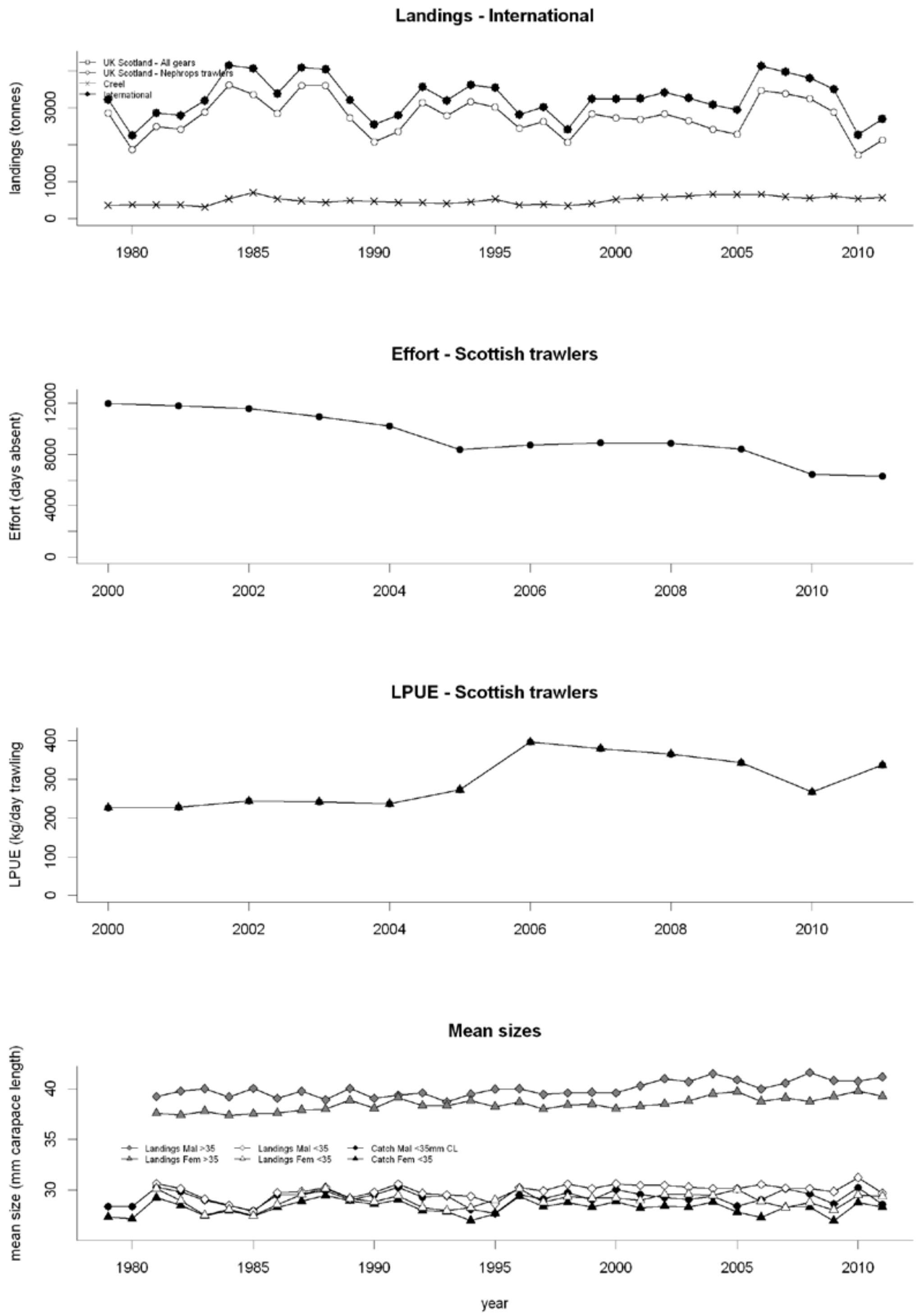

Figure B1-1. ***Nephrops*, North Minch (FU11). Long-term landings, effort, lpue and mean sizes. The interpretation of the lpue series is likely to be affected by the introduction of the "buyers and sellers" regulations in 2006.**

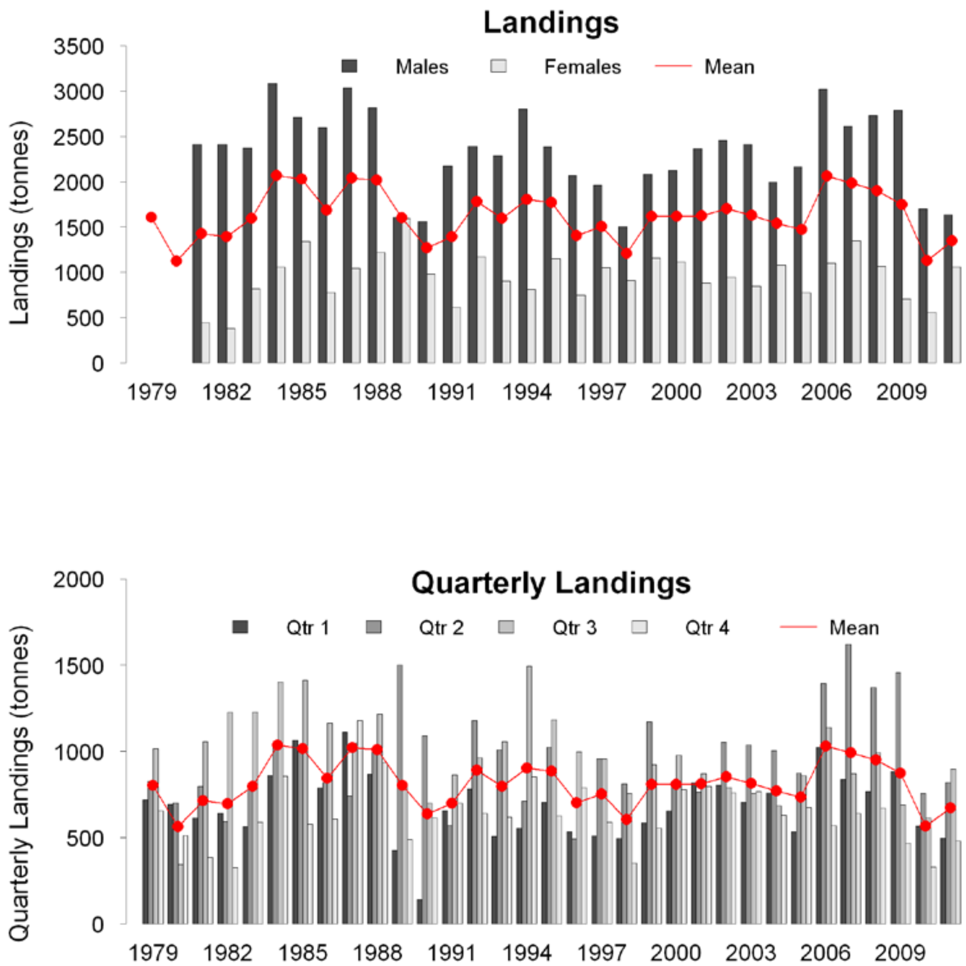

Figure B1-2. ***Nephrops,*** **North Minch (FU11). Landings by quarter and sex from Scottish trawlers.**

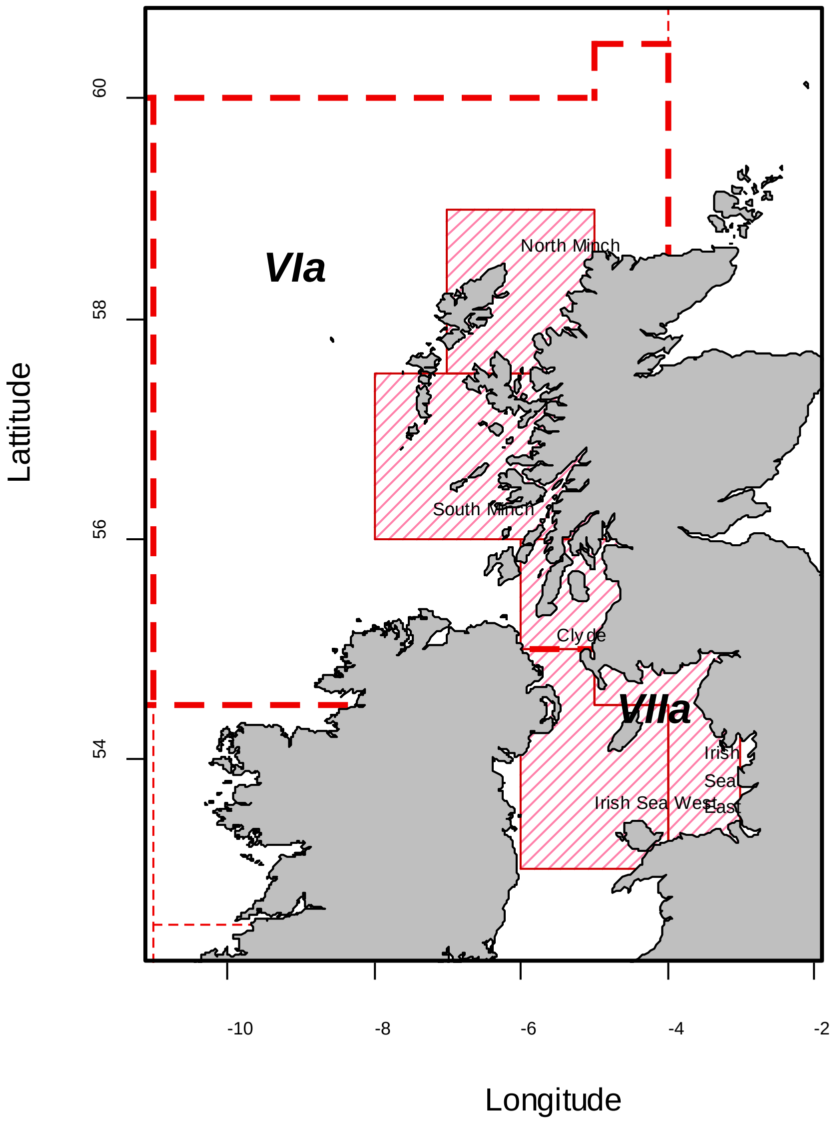

Figure B1-3. ***Nephrops*** **Functional Units in VIa and VIIa. North Minch (FU11), South Minch (FU12), Clyde (FU13), Irish Sea East (FU14) and Irish Sea West (FU15).**

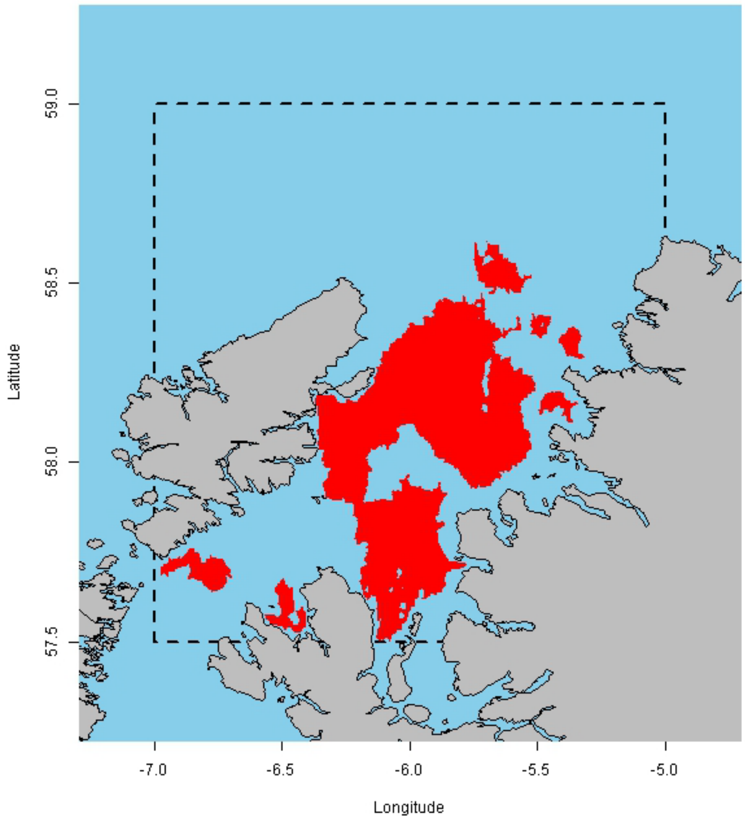

Figure B1-4. ***Nephrops*****, North Minch (FU11).** ***Nephrops*** **ground area (shown in red) estimated using VMS data (2908 km²).**

Stock Annex for FU32 Norwegian Deep

Stock	Norwegian Deep *Nephrops* (FU32)
Working group	ICES Working Group on the Assessment of Demer sal Stocks in the North Sea and Skagerrak (WGNSSK)
Date	28/04/2013
Author	Guldborg Søvik

A. General

A.1. Stock definition

Throughout its distribution, Norway lobster (*Nephrops norvegicus)* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows. Therefore, the distribution of *Nephrops* is largely defined by the distribution of suitable sediments. Adult *Nephrops* only undertake small-scale movements, but larval drift may occur between separate mud patches in some areas. No information is available on the extent of larval mixing between the *Nephrops* stock in FU 32 and the neighbouring stocks in Skagerrak (FU 3) and Fladen Ground (FU 7).

The Norwegian Deep is located in the eastern part of ICES Division IVa. Its western boundary is adjacent to the Fladen Ground, while the Norwegian coast constitutes its eastern boundary. *Nephrops* has been caught on most trawl stations of the Norwegian annual shrimp survey covering the area. This indicates that the species is widely distributed in FU 32, but the exact distribution is not known. Sediment maps of the Norwegian Deep indicate that most of FU 32 consists of sediments suitable for *Nephrops*.

A Scandinavian Interreg project, ØBJ-FISK (2012–2014), will investigate the genetic stock structure of *Nephrops* in the Norwegian Deep/Skagerrak/Kattegat area. By the end of 2014 it will be concluded whether FU 32 can still be considered a separate stock or not.

A.2. Fishery

Traditionally, Danish and Norwegian fisheries have almost exclusively exploited this stock, while exploitation by UK vessels has been insignificant. Since 2000, Sweden has landed small amounts. The majority of the landings in FU 32 are taken by Denmark. From 1995 to 2007 the Danish share of the landings was between 80 and 90%. With the steady decrease of the Danish landings since 2006 the Danish share has decreased accordingly, to 70–75% since 2008. The decline is due to several factors: increasing fuel costs, fewer vessels rendering it more difficult to exchange information on the current *Nephrops* locations, and, following the change in mesh size legislation in 2002 (see below), most Danish *Nephrops* landings from FU 32 are now mainly bycatches from mixed fisheries.

Norwegian landings have decreased by 50% from 2008 to 2011–2012, due to a decrease in landings from trawls. As a substantial part of the Norwegian *Nephrops* landings are taken as bycatch in shrimp trawls, the very poor shrimp fishery in the Norwegian Deep in recent years may explain the low *Nephrops* landings from shrimp trawls (decreasing from 60–70 t in 2008–2009 to only 9 t in 2011–2012). Changes taking place over several years, like the increased use of sorting grids in shrimp trawls, resulting in less *Nephrops* being caught, and a discontinuation of the Norwegian directed *Nephrops* fishery due to the new mesh size regulations, may also explain the decrease in *Nephrops* trawl landings.

Sediment maps indicate that the area of suitable sediment for *Nephrops* is larger than the current extent of the fishery, and there may be possibilities of expansion into new grounds on which *Nephrops* is not currently exploited or only slightly exploited. These grounds are mainly found along the Norwegian coast.

Danish fishery

Nephrops are fished all year-round by the Danish fleet. The Danish *Nephrops* fishery occurs almost exclusively along the western slope of the Norwegian Deep and is comprised solely of bottom trawls. Due to changes in the management regime (mesh size regulations regarding target species) in the Norwegian zone of the northern North Sea in 2002, there was a switch to increasing Danish effort targeting *Nephrops* in the mixed fisheries in the Norwegian Deep. However, a distinction between the fishing effort directed at *Nephrops*, roundfish or anglerfish (*Lophius piscatorius*) is not always clear. The mesh size in the trawls catching *Nephrops* is >120 mm. The use of twin trawls has been widespread for many years. The annual *Nephrops* TAC for the EU (Danish) fisheries in the Norwegian zone has never been a constraint to these fisheries.

Norwegian fishery

Nephrops are fished all year-round by the Norwegian fleet. The *Nephrops* fishery north of 60°N (with 16–36% of the Norwegian FU 32 landings (2001–2012)) is mainly a creel fishery, with varying amounts of landings from *Nephrops* trawls. The fleet consists mainly of small vessels <11 m. South of 60°N, the fleet structure has changed from 2007 to present, with an increase in small vessels and a decrease in larger ones, resulting in the fleet in 2011 and 2012 being dominated by vessels <15 m. The change can be explained by a growing trap fishery, which is carried out mainly by vessels <15 m. Due to the new mesh size regulations, there is no longer a directed Norwegian *Nephrops* trawl fishery in FU 32. *Nephrops* are now caught in a mixed fishery and in 2012 made up 19% of the commercial landings from bottom trawl south of 60°N. Landings per ICES statistical rectangle (available from 2009) provide information on the spatial distribution of the *Nephrops* fishery. In 2009–2010 the fishery was located more offshore compared with 2011 and 2012, which is in accordance with the increase in the coastal trap fishery. Trawl positions from electronic logbooks show that the large vessels operated mainly along the western and southern edges of the Norwegian Deep in 2011 and 2012. The recreational trap fishery for *Nephrops* along the Norwegian coast has increased in recent years.

Regulations

The EU fisheries are managed through a TAC, determined at annual EU-Norway negotiations. The TAC has never constrained the EU fisheries. In 2005, 98% of the quota was taken, but since 2009, only 20–30% has been fished. There are no Norwegian quotas.

Following negotiations between Norway and EU the management regime (mesh size regulations regarding target species) in the Norwegian zone of the North Sea was changed in 2002 with minimum legal mesh size being set to 120 mm for all large mesh trawl fisheries. Before 2002, fishing for *Nephrops* was allowed using mesh sizes down to 70 mm, but as *Nephrops* is considered bycatch in a mixed fishery using bottom trawls, the special regulations regarding this species were removed in 2002. According to the Norwegian fisheries organization, the directed trawl fishery for *Nephrops* in this area disappeared with the introduction of the 120 mm mesh size.

The minimum landing size (MLS) is 40 mm CL, which is higher than the minimum landing size of 25 mm CL in the rest of the North Sea (EU legislation). This is part of an agreement between Norway, Sweden and Denmark and is set mainly due to market reasons. Size can also be measured as total length (MLS of 130 mm). Norwegian *Nephrops* landings may consist of up to 10% in numbers below MLS. In the Norwegian zone in the North Sea it is illegal to trawl for *Nephrops* within the 4 nm border, and it is illegal to fish with more than two trawls (twin trawls).

A.3. Ecosystem aspects

Nephrops directed trawl fisheries are characterized by large amounts of non-commercial bycatch species and *Nephrops* below MLS. However, in FU 32 *Nephrops* are caught in a mixed fishery where the amount of *Nephrops* below MLS is small due to the legislated mesh size of 120 mm. The *Nephrops* discard mortality from trawl fishing is considered to be high (75%) (Wileman *et al.*, 1999), while it is basically zero in creel fisheries (ICES 1998).

Nephrops is omnivorous and eats crustaceans, molluscs and polychaetes as well as dead and decaying plant and animal matter. Recently, *Nephrops* have been found to ingest plastic strands (Murray and Cowie, 2011). *Nephrops* is preyed upon by many species of demersal fish, like cod.

The species occurs south to Morocco, which suggests that it might tolerate increased sea temperatures in the northern part of its distribution range. The 1st quarter annual bottom mean temperature in FU 32 (from the Norwegian shrimp survey) has varied between 6.5 and 8.0°C in 2006–2012, while salinity has varied between 35.15 and 35.25‰ in the same time period.

B. Data

B.1. Commercial catch

On-board sampling of Danish catches (split into discard and landings components) have been carried out by Danish observers since 1997 (Table B.1.1), providing information on length distribution and sex ratio. For 2008–2009 sex-specific data do not exist as the observers pooled data on males and females. Due to changes in the Danish at-sea-sampling programme implemented in the second quarter of 2011, where observer trips were randomly drawn from all fishing trips, only one trip was sampled within FU 32. This was due to the very few Danish fishing trips in FU 32. The at-sea-sampling programme was changed in 2012, resulting in a satisfactory number of at-sea-sampling trips.

On-board sampling of catches as part of inspections (not split into discard and landings components) have been carried out by the Norwegian coast guard, mainly on Danish trawlers, since 2005 (Table B.1.2). There were however, no CL data in 2010 and very limited data in 2005 and 2009. The coast guard tend to measure catches by total length (TL).

Since 2003 the Danish at-sea-sampling programme has provided data for discard estimates. However, the samples have not covered all quarters. There were no discards data for 2008 and 2011. The Danish discard-to-landings ratio is considered unsuitable for estimating Norwegian discards, as the fisheries in the two countries take place partially on different fishing grounds and by different gears. For a description of the Danish sampling programme, see Feekings *et al*. (2012).

Table B.1.1. Number of observer trips per year by the Danish at-sea-sampling programme in FU 32, with total annual number of hauls and number of *Nephrops* in samples of discards and landings. No data were obtained in 1999 and 2001.

Year	Number of trips	Number of hauls	Number of *Nephrops* in discard sample	Number of *Nephrops* in landings sample
1997	4	31	5228	41
1998	1	2	0	204
1999				
2000	2	20	146	3760
2001				
2002	5	38	1849	3125
2003	3	27	2617	3344
2004	5	28	2619	3484
2005	3	23	1565	2108
2006	5	17	1498	2169
2007	6	25	1746	2690
2008	8	45	2492	5489
2009	5	19	598	2030
2010	6	21	1122	2466
2011	1	5	0	384
2012	5	20	1369	2976

Table B.1.2. Annual number of inspections (samples) by the Norwegian coast guard of Danish and Norwegian trawlers with *Nephrops* in the catches, and number of *Nephrops* in the catch samples. No data were obtained in 2010.

Year	Number of samples	Number of *Nephrops* in samples
2005	1	118
2006	11	1399
2007	9	1345
2008	10	1462
2009	1	182
2010		
2011	12	1856
2012	4	401

B.2. Biological

Possibilities for obtaining biological data from the Danish at-sea-sampling programme, like weight–length and maturity data, will be investigated.

A data collection programme from the recreational trap fishery along the Norwegian coast was initiated in 2012, and this is expected to provide data on sex ratio, discard ratios, length–frequency distributions, and the reproductive cycle.

B.3. Surveys

The annual Norwegian shrimp survey initiated in 1984 (Campelen 1800/35 bottom trawl with rock-hopper gear, and codend mesh size of 22 mm with 6 mm lining net) covers most of FU 32. The catches of *Nephrops* in the survey trawl have earlier been considered too small and variable to provide a reliable biomass index, but the *Nephrops* benchmark in 2013 (WK*NEPH* 2013) suggested that the survey data should be investigated more closely. Possibilities for establishing a biomass index time-series will be investigated before the 2014 working group meeting.

B.4. Commercial lpue

A landings-per-unit-of-effort (lpue) time-series is available from the Danish trawl fleet. The Danish logbooks contain information on catches per vessel, trip, day, and ICES square. Information on gear is not consistent and is often the main gear used by the vessels. There is no information on mesh size. Lpue is estimated using officially recorded effort (days fished). There is no account taken of any technological creep in the fleet.

The Danish catch and effort data have been analysed and standardized to provide indices of stock biomass. A GLM standardization of the lpue series was performed on all fishing trips where *Nephrops* was caught conducted in the period 2000–2012:

$$\ln(lpue) = \ln(lpuemean) + \ln(a*Hp) + \ln(year) + error$$

where a is the linear coefficient of the relationship between lpue and the vessel engine power (horsepower), the 'year' factor covers the period 2000–2012, and the variance of the error term is assumed to be normally distributed.

Norwegian logbooks contain only information from trawl hauls, not traps. The logbook catches from FU 32 constitute 17–59% of the trawl landings in 2000–2012. Electronic logbooks compulsory for all vessels ≥15 m were introduced in 2011. These logbooks have a better resolution of the data, with catches per haul, and information on haul position, and both type and number of gear. The use of the various gear codes by fishers is not always consistent. Bottom and *Nephrops* trawls, as well as bottom and shrimp trawls, seem to some degree to be used interchangeable in the logbooks, irrespective of the actual gear being used. Large mesh bottom trawl and shrimp trawl can be distinguished based on mesh size. This was not possible in 2011–2012 due to lack of information on mesh size, and shrimp and bottom trawls were distinguished based on target species (shrimp vs. *Nephrops*/demersal fish). Twin shrimp and twin bottom trawl (both recorded as "twin trawl" in 2000–2010) can be distinguished based on mesh size. However, the use of twin trawl prior to 2011 is probably not always correctly recorded.

The data from bottom trawls prior to 2011 are considered unsuitable for lpue analyses mainly because one particular vessel, with 70–100% of the logbook catches in 2003–2008, has strange recordings of haul duration in 2005–2007 resulting in very high mean lpue values, which cannot reflect the state of the stock (WK*NEPH* 2013). The data from shrimp trawls prior to 2011 are also considered unsuitable for lpue analyses due to lack of data in some years and concern that varying *Nephrops* catch rates in shrimp trawls may reflect more the choice of shrimp grounds than the state of the

Nephrops stock. From 2011 onwards trawl haul positions are given in logbooks such that the spatial distribution of vessels fishing with shrimp and bottom trawls can be compared and the overlap between shrimp and *Nephrops* grounds elucidated. With the introduction of Norwegian electronic logbooks compulsory for all vessels ≥15 m length in 2011, two new time-series from bottom and shrimp trawls (single and twin) will be established from 2011 onwards. However, as a large portion of the Norwegian fleet landing *Nephrops* in FU 32 consists of vessels <15 m, especially north of 60°N, the Norwegian logbook data available for analysis will continue to be limited.

C. Historical stock development

None.

D. Short-term projection

None.

E. Medium-term projections

None.

F. Long-term projections

None.

G. Biological reference points

None specified.

H. Other issues

All data-limited *Nephrops* stocks without UWTV-surveys are now assessed based on a new approach outlined in 2012. The spatial extent of the *Nephrops* grounds in FU 32 has been estimated to provide a likely envelope for the total abundance of *Nephrops* in FU 32. UWTV-survey information on the mean density of *Nephrops* (minimum value of 0.1 animals/m^2), from the neighbouring functional unit (FU 7 Fladen Ground), was used together with the mean discard percentage in Danish catches in 2003–2012 (17%) and mean weight of *Nephrops* in the Danish catches in 2012 (69 g). The total area of the *Nephrops* grounds in FU 32 have been estimated in two ways, 1) using information on the geographic distribution of the Norwegian and Danish fisheries, as well as suitable sediment (55 500 km^2), and 2) a more conservative estimate using the area of the Danish fishing grounds (based on VMS data) (20 000 km^2). Estimate 1) is used in the 2013 assessment. The biomass estimates imply very low harvest ratios in FU 32 (≤1%), even in former years with high landings (1000–1200 t).

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