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Report of the Benchmark Workshop on *Nephrops* Stocks (WKNEP)

24–28 October 2016

Cadiz, Spain

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Contents

1 Executive summary

This benchmark was convened to consider five different functional units for *Nephrops*. FU32 (Norwegian Deep), FU3–4 (Skagerrak & Kattegat), FU 22–23 (Bay of Biscay), FU 28–29 (Portugal) and FU 30 (Gulf of Cadiz).

A data evaluation meeting for the stocks was held in Lisbon, Portugal to collate the available data and plan the remaining work before the main benchmark meeting in Cadiz, Spain.

FU28–29 could not be covered in the main benchmark meeting and is scheduled to be covered by correspondence during 2017. The remaining FUs were presented to the Benchmark group.

FU32 was the only stock not to be assessed with an underwater TV survey. The benchmark updated biological data, revised the stock area definition and explored the use of additional survey indices.

For FU 22–23, the main focus of benchmark activity was to review the new UWTV survey and determine its suitability as the primary tool for stock assessment. Upon review the Group approved the survey for use as the basis for stock assessment. Analytical determination of an MSY appropriate harvest rate was not considered possible.

For FU 3-4, several amendments to the existing UWTV survey based method were evaluated and approved. For the stocks in FU 23–24 and FU 30, the WKNEP concluded that the UWTV survey method, as described in the stock annex is appropriate for providing scientific advice on the abundance of these stocks. However, for both these stocks, the common length-based yield per recruit method for deriving reference points, and hence translate the stock abundance estimate to recommended removals, was not satisfactory. The group therefore considered what might be appropriate intermediate extraction rates based upon the history of the affected FUs and the performance of other *Nephrops* fisheries.

In relation to the issues surrounding the analytical approach to reference point setting, WKNEP proposed an interim solution, but recommends that ICES establishes a study group to examine methods to derive recommended removals in stocks where the abundance estimate comes from other sources than an analytic assessment. Although *Nephrops* monitored with UWTV surveys perhaps is the most obvious example at present, a study group can have a broader scope.

2 Introduction

Over some years, there has been a development towards UWTV surveys as the main source of information about stock abundance for *Nephrops* in European waters. The present workshop considered that approach for two new stocks, in FU 23–24 and FU30, and amendment of the existing assessment for FU 3–4. The status of FU 32 was also considered, but any reliable assessment for this stock is out of reach due to the lack of data. FU 28–29 was also scheduled for the present benchmark but had to be postponed to finalize necessary preparatory work.

For each of the stocks with UWTV surveys, the group considered in detail:

- the technology of the survey, including correction for edge effects, discovery rate, species identification, etc.;
- the distribution area and coverage;
- the derivation of a recommended harvest rate.

For all these stocks the WGNEPH considered, and the reviewers endorsed, that with regard to the first two bullet points, the UWTV survey based assessment as described could be standard for the future. When attempting to derive reference points, with what is deemed to be an accepted method for such stocks, unexpected problems were uncovered that could not be solved at the meeting. This is further discussed below.

For FUs 3–4, UWTV surveys have been used for several years to assess the stock, and the present benchmark was mostly to endorse improvements and refinements. The WKNEP agreed that the proposed changes were acceptable.

Some specific issues:

2.1 Reference points

The key reference point for managing a stock with UWTV survey assessment is the recommended harvest rate, as a measure of exploitation. The guidance for that should be a proxy for F_{MSY}, which may be $F_{0.1}$, $F_{35\%SPR}$ or F_{MAX} if that is sufficiently well defined. The approach, in line with what has been done for other stocks, was to use a length-based steady state population model to obtain yield per recruit curves. The main tool used was the SCA software, which is a standard length-based equilibrium model with fixed parametric selection that is fitted to the length distribution of the catches. For a number of other stocks, one can simply calculate a yield per recruit from growth and selection parameters and assumed natural mortalities, with what appears to be sensible parameter values according to literature and occasional local observations. These may not be well parameterized, but tend to give reference points that are in line with what would commonly be regarded as reasonable.

For the stocks in FU 23–24 and FU 30, WKNEPH compared the abundance estimates from the SCA model with those estimated by the survey, and found large differences. As a result, harvest rates derived from the SCA lead to much larger recommended catches than experienced historically because of the larger population estimate from the UWTV survey. The problems could be amended to a variable extent in numerous ways, but in particular by increasing the natural mortality in the SCA model, which again would have an impact on the reference points and subsequently on the harvest rate to be recommended.

It was also realized that the length distributions, in particular in FU30, declined stepwise towards larger length, which would not be compatible with constant growth and mortality for those lengths. Attempts to estimate mortality with the Jones cohort analysis indicated a declining F towards larger lengths for both sexes, although with different patterns, which, assuming a constant natural mortality, violates the assumption of flat selection at-length. For FU3–4, two different but similar models were applied (SCA and SLCA) and the results were comparable.

The WKNEP found the issue of poor model fits (assuming M of 0.2 and 0.3) severe enough to preclude a routine application of standard methods, as it was unable to decide on adequate growth and mortality parameters. Results suggested that M should have been higher, for example, in the order of 0.4–0.5. This is not unique to *Nephrops* stocks, and this was reaffirmed here. The model parameters originate from general literature and occasional local observation. To ensure consistent standards, the WKNEP decided to recommend initiating the development of common guidelines for how to derive MSY and precautionary reference points for the exploitation of *Nephrops* that are assessed with UWTV surveys.

The conclusion, which was supported by the reviewers, was to present reference points derived from historical experience from similar previously assessed stocks as an interim solution. While these harvest rates were chosen deliberately on the precautionary side, their application still imply a major increase in landed catch, given that the UWTV surveys currently indicate that both these stocks are lightly exploited. A gradual transition towards higher TACs was recommended, but the exact design of such a regime would have to consider economic and social aspects that are outside the remits of the benchmark group.

2.2 Natural mortality

Part of the SCA model output is an estimate of the absolute stock abundance. This method gave stock estimates far below those of the UWTV survey and correspondingly higher harvest rates. While a reasonable fit could be obtained by manipulating input parameters, the SCA model typically required a higher natural mortality than normally assumed for European *Nephrops* stocks. However, a new length-based methodology has been developed to estimate F and M simultaneously for multiple *Nephrops* stocks. When five *Nephrops* stocks were input into this hierarchical mean length and effort model, new estimates of M were produced for each stock and sex. These results also suggested that higher natural mortalities may be required for four out of five stocks.

Therefore, there clearly are indications that the natural mortality may be higher for some *Nephrops* stocks than previously assumed. However, there is not only uncertainty in the values of natural mortality, but also in the assumed growth parameters and the shape of the length selectivity in the fishery. All of these factors can affect the shape of the catch-at-length distribution, and in the SCA model, can produce different magnitudes of stock abundance.

WKNEP spent some time considering if high Ms on the order of 0.4 and higher could be valid, and in fact, where the original assumption of 0.2 and 0.3 came from. Although a higher natural mortality may be realistic, this requires further validation given that natural mortality is so poorly known. It is recommended that this is done as part of a broader exploration of methods to translate UWTV measured abundance into advice, by harvest rates derived from yield per recruit or by other approaches.

There is also a concern that the higher natural mortality assumption may lead to unwarranted increases in exploitation, as $F_{0.1}$ goes up with a higher M.

2.3 Spatial definition

On some occasions, areas that were not covered by the surveys, were identified. It was agreed that if these areas contributed little to the fishery and hence the total stock abundance, then they should be ignored. While this may lead to a small underestimate of the total stock, it would not be unduly restrictive to the fishery. The alternative would be to postpone the transition to UWTV survey assessments, which was not recommended.

2.4 Survey index

In relation to FU 32, the WKNEPHS requested that estimates of relative biomass be presented at a finer spatial scale. Originally, the index was modelled with Skagerrak and the Norwegian Deep as having combined trends. The index was recreated with the two areas separated, and reviewed by the group. The results from the two runs were similar, but WKNEPHS concluded that the separated area approach was more appropriate.

2.5 Life-history parameters

It became clear that the uncertainty in life-history parameters (growth, natural mortality) for *Nephrops* is contributing to current model outputs. Therefore, the reviewers suggest future consideration of regionally-specific estimates of growth (specifically von Bertalanffy growth parameters) that reflect local population dynamics. Additionally, results from the hierarchical mean length and effort model suggest that natural mortality can be highly variable for *Nephrops*, and that for several functional units it may be higher than the 0.2 and 0.3 that was previously assumed. Thus, in the future it would be useful to validate natural mortality of *Nephrops* at the functional unit level.

For FU 30, there is some question about sample sizes in the length–frequency distributions, and the data appear to be quite noisy. Given the high dependence of length frequencies in length-based models (the SCA model as well as others), there's a continued need to ensure appropriate samples as data input.

2.6 Conclusions

The greatest challenge for this benchmark was the determination of appropriate reference points for FUs 23-24 and 30 where the length cohort model approach did not provide a satisfactory fit to all available data. It was not possible within the meeting to derive a new analytical approach to estimation of reference points and therefore the group arrived at a more pragmatic solution although it is realised that this does not fit within the existing ICES frameworks. Taking a view across the other *Nephrops* stocks for which there are established reference points, the F0.1 proxy gives Harvest Rates in the region of 10% and it was therefore considered reasonable to aim towards this level in the longer term. Given the considerable distance between the currently observed HR for FUs 23-24 and FU30 there was concern that jumping straight to a 10% HR is risky when there is uncertainty around aspects of stock dynamics. It is therefore recommended that a staged approach to increasing target HRs is taken, with time to monitor the response of the stock to any increase.

For FU23-24, the current harvest rate is ~5.5%, so moving to a 10% rate would be an 80% increase. The group considered that moving half way (~7.7%) in the first instance would be a not-unreasonable compromise although there is no analytical basis to this suggestion.

For FU30 the observed HR has ranged between 1.5% (2010–2012) and 4.0% when landings achieved the highest value (2003). The most recent period 2013–2015 saw exceptionally low HR due to TAC restrictions. In others routinely UWTV surveyed stocks of similar density level the currently estimated harvest rate fluctuates around 6% which is well above the levels that this stock has experienced. WKNEP therefore recommends setting an initial F_{MSY} proxy to 4% and moving gradually towards this level.

Adoption of the agenda

	AM	PM
24/10/16	10:00 start Introductions Updates on progress since data meeting	Hierarchical mean length model FU3–4
25/10/16	FU32	FU28–29
26/10/16	FU30	Sub-groups: FU23–24 survey Reference point proxys
27/10/16	FU32	Report writing
28/10/16	Report writing	Report writing Recommendation discussion 16:00 Close

3 Issue lists

3.1 *Nephrops* in 3.a

Stock	Nep IIIa	
Stock coordinator	Name: Mats Ulmestrand	Email: mats.ulmestrand@slu.se
Stock assessor	Name: Jordan P. Feekings	Email: jpfe@dtu.aqua.dk
Data contact	Name:	Email:

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be considered and/or quantified [1]	Redefine area of all subareas using up to date information.	Compile available data sources from all available years.	DK & SW VMS data, SW logbook data from <12 m vessels and creel vessels, sediment maps, etc. Data are available.	
	Create UWTV reference footage.	Review selection of UWTV footage and establish consensus counts	UWTV survey footage. Data are available	
Tuning series	Standardize Swedish lpue.		Logbook data are available.	

[1] Include all issues that you think may be relevant, even if you do not have the specific expertise at hand. If need be, the Secretariat will facilitate finding the necessary expertise to fill in the topic. There may be items in this list that result in 'action points for future work' rather than being implemented in the assessment in one benchmark.

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Discards	Effects of changing the MLS Effects of a landing obligation Effects of discard survival estimates	Bio-economic analysis of changing the MLS for *Nephrops*.	VMS, landings, discards, stock estimates, price data, biological data (e.g. size and sex distribution, female and male maturity, discard survival).	
Biological parameters	Growth parameter update Length–weight update			
Assessment method	The UWTV survey method is not possible for creel areas. Possible inclusion of a length-based assessment model to compliment the UWTV survey.	Develop and finalize a length-based model for *Nephrops*.	Catch data. Data are available for trawled and creeled areas.	Anders Nielsen, DTU Aqua
Biological reference points		Model work should provide these reference points.	Proxies for F_{MSY} exist from LCA. $B_{trigger}$ estimate requires a longer UWTV time-series.	

3.2 *Nephrops* in FU 32

3.2.1 Data needed

- Danish data from at-sea-observers (discard, lfd, sex ratio)
- Danish log book data
- Norwegian shrimp survey data
- Norwegian electronic log book data
- Norwegian data from recreational *Nephrops* fishery
- Norwegian Coast Guard data from vessel inspections

3.2.2 Current assessment issues

Danish data

- Investigate possibilities for obtaining biological data (maturity, weight, length) from the Danish at-sea-observer programme
- Analyze discard data (strange values in recent years), document old and new sampling procedures, agree on standard sampling procedure
- Analyze spatial distribution of Danish fishery

Norwegian data

- Explore possibilities for obtaining a *Nephrops* biomass index from the survey data
- Analyze biological data from recent studies on recreational fishery along Norwegian coast (sex ratio, length)
- Analyze so far unused total length data (TL) from Coast Guard inspections
- Investigate possibilities for obtaining discard data from Coast Guard inspections
- Explore the area calculations used for estimating harvest rates. Is the current estimated area too large?
- Explore electronic logbook data from 2011 onwards and establish new lpue time-series from respectively shrimp and *Nephrops* trawls.

3.2.3 Proposed working papers/analyses

Working paper 1: Danish at-sea-observer programme: documentation of procedures and possibilities for obtaining biological data.

Working paper 2: New biomass index time-series from Norwegian electronic logbook data.

Working paper 3: A new biomass index from the Norwegian annual shrimp survey in the Norwegian Deep?

Working paper 4: Exploration of Norwegian Coast Guard inspections data: discard and length–frequency distributions.

Working paper 5: Biological data from recent studies of the Norwegian recreational fishery - do the coastal *Nephrops* differ from animals on offshore fishing grounds?

3.2.4 Workplan

Most of the work will be done autumn 2015 and spring 2016, before the data workshop. Jordan Feekings will work on the Danish discard data and participate in discussions on the area estimates. Guldborg Søvik will analyze the Norwegian data, with the aid of colleagues at IMR.

3.3 *Nephrops* in FU 23–24

STOCK	*NEPHROPS* FU 23–24	
Stock coordinator	Name: Spyros Fifas	Email:Spyros.Fifas@ifremer.fr
Stock assessor	Name: Spyros Fifas	Email: Spyros.Fifas@ifremer.fr
Data contact	Name: Spyros Fifas, Michèle Salaun	Email: Spyros.Fifas@ifremer.fr, Michele.salaun@ifremer.fr

Issue	Problem/Aim	Work needed /possible direction of solution	Data needed to be able to do this: are these available/ where should these come from?	External expertise needed at Benchmark type of expertise /proposed names
(New) data to be considered and/or quantified2	UWTV survey data for years 2014 and 2015 (planned for July 2015)	Spatially structure models	Data provided from LANGOLF survey (series 2006–2013)+DCF sampling onboard (since 2003)+UWTV survey data (2014–2015)	
Tuning series	Commercial tuning fleet (district of Le Guilvinec 2nd quarter, years 1987–2013)+twin trawl survey LANGOLF (years 1987–2013) not carried out from 2014 onwards	Investigation aiming to include another tuning series corresponding to the Southern part (outside Brittany) of the fishery	Data provided by fishing industry representative	

[2] Include all issues that you think may be relevant, even if you do not have the specific expertise at hand. If need be, the Secretariat will facilitate finding the necessary expertise to fill in the topic. There may be items in this list that result in 'action points for future work' rather than being implemented in the assessment in one benchmark.

Issue	Problem/Aim	Work needed /possible direction of solution	Data needed to be able to do this: are these available/ where should these come from?	External expertise needed at Benchmark type of expertise /proposed names
Discards	DCF sampling plan covering period since 2003+sparse years (1987, 1991, 1998). For validation of the discard derivation method applied on missing years see IBP*Nephrops* 2012	Additional investigations have to be undertaken on the actual impact of selectivity devices adopted since 1st April 2008 (not enough data for the moment)	DCF samples since 2003	
Biological Parameters	Validation of discard survival rate either as used by WGHMM (WGBIE) for the whole historical series or as updated by recent experiments (higher value of the survival rate)	Spatial variability of female maturity ogives (GLMs vs. compacity of the sediment, depth, etc.)	Maturity database as filled in since 2004–2005	
Assessment method	The IBP 2012 concluded the inadequancy of the CSA (Collie-Sissenwine analysis) because of unlikely variability of predicted SSB and recruitment indices. The XSA assessment was retained although it should be replaced by alternative approaches (length structured models?) or by UWTV survey (nevertheless, this method limits unibiased investigations only on the adult component of *Nephrops* stocks)			
Biological Reference Points	N/A			

3.4 *Nephrops* in FU 28-29

STOCK	*NEPHROPS* FU 28-29	
Stock coordinator	Name: Cristina Silva	Email: csilva@ipma.pt
Stock assessor	Name: Cristina Silva	Email: csilva@ipma.pt
Data contact	Name: Cristina Silva	Email: csilva@ipma.pt

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be considered and/or quantified[3]	Additional M - predator relations Prey relations Ecosystem drivers *Other ecosystem parameters that may need to be explored?*			
Total Catch	Only landings from Portuguese fleet are available in most of the years -> unaccounted mortality Possible separation by Functional Unit?	Review and estimate total catch and total effort	Historical data from Spanish Fleet in these FUs (landings, logbook data) Spatial data (VMS) Portuguese data available	

[3] Include all issues that you think may be relevant, even if you do not have the specific expertise at hand. If need be, the Secretariat will facilitate finding the necessary expertise to fill in the topic. There may be items in this list that result in 'action points for future work' rather than being implemented in the assessment in one benchmark.

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Tuning series	- Fishery targeting two main species of crustaceans, deep-water rose shrimp and Norway lobster, sharing only partly the same grounds. In periods of high abundance of rose shrimp the vessels spend less effort on *Nephrops*. - Crustacean trawl survey	- Standardized cpue series for *Nephrops* related to area/depth, other species dependency - Estimate abundance/biomass for fishing areas	All data available: - Logbooks, VMS data - Crustacean survey series	
Discards	Discarding is minimal in this fishery. Not an issue			
Biological Parameters	Growth parameters and natural mortality estimated by tagging in 1990. Attempts to include a joint tagging programme for several *Nephrops* FUs in DCF not successful due to high costs.			

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Assessment method	No analytical assessment approved. XSA, used until 2011, accepted only for trends. The use of standardized cpue has reduced the residuals in catchability and the retrospective pattern but problems of internal consistency remain (IBP, 2012) ICES DLS approach used since 2013	Explore: 1. Length based assessments with different methods (LCA, SS3, ...) 2. Age-based assessments using slicing (for comparison) 3. A number of approaches, including trawl surveys, length composition information, and basic fishery data such as landings and effort.	Data available: - Landings (partial, missing Spanish data) - Cpue - Survey indices - Length distribution - Maturity - Weight–length relationship - Spatial distribution	Helen Dobby/Richard Methot/Jim Ianelli
Biological Reference Points	No BRPs adopted	BRPs (Y/R) or proxies depending on the assessment approach		

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Management issues	- Crustacean fishery directed at rose shrimp and Norway lobster. Norway lobster is the 2nd target species, its importance increases in periods of low abundance of rose shrimp. - Recovery Plan for Southern Hake and Iberian *Nephrops* stocks since 2006. No objectives defined for *Nephrops* in this plan. 10% reduction in F for Southern Hake resulted in 10% reductions in TAC and effort for *Nephrops* every year.	- Understand the fisheries dynamics and the dependence from rose shrimp. - Unlink *Nephrops* management from Southern Hake recovery. - Set management objectives for *Nephrops*, taking into account the characteristics of the crustacean fishery.		

3.5 *Nephrops* in FU 30

Stock	*Nephrops* FU 30	
Stock coordinator	Name: Yolanda Vila	Email: yolanda.vila@cd.ieo.es
Stock assessor	Name: Yolanda Vila	Email: yolanda.vila@cd.ieo.es
Data contact	Name: Yolanda Vila	Email: yolanda.vila@cd.ieo.es

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be considered and/or quantified[4]	Additional M - predator relations Prey relations Ecosystem drivers Other ecosystem parameters that may need to be explored?			
Tuning series	- Métier highly multispecific. Directed effort estimated from trips with at least 10% *Nephrops* landings. - Trawl survey_ARSA_(SPGF-cspr-WIBTS-Q1) but it is directed to demersal species in general and not to *Nephrops*	- VMS and logbooks analysis.	VMS are available for 2011–2013 periods. For other year it should be supplied by the Spanish Administration (Secretaría General de Pesca, SGP). Logbooks available	

[4] Include all issues that you think may be relevant, even if you do not have the specific expertise at hand. If need be, the Secretariat will facilitate finding the necessary expertise to fill in the topic. There may be items in this list that result in 'action points for future work' rather than being implemented in the assessment in one benchmark.

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Discards	Discarding is negligible in this fishery. Not an issue			
Biological Parameters	There is no information about growth parameters and natural mortality in this FU. Maturity ogives are available from 2004, 2009, 2010 and 2011.		Biological parameters information of others FUs	
Assessment method	No analytical assessment	- UWTV survey approach. UWTV exploratory survey was carried out in 2014. However, improvements must be performed in next survey. Annual UWTV will be carried out from 2015.	*Nephrops* UWTV survey will be carried out in June 2015 Data available: - Landings - Lpue - Trawl survey indices - Length distributions - Maturity - Weight–length relationship	Colm Lordan/Jennifer Doyle/Helen Dobby
Biological Reference Points	N/A		Trawl survey_ARSA__(SPGF-cspr-WIBTS-Q1)information available	
Data to be considered	Identification of other burrowing species associated to the *Nephrops* ground	Analysis of the spatial distribution and abundance in Trawl survey_ARSA_(SPGF-cspr-WIBTS-Q1) -Trawls during UWTV survey		

4 Scorecard on data quality

The accuracy (potential bias) of input data for the assessment is evaluated according to the scorecard developed by the Workshop on Methods to Evaluate and Estimate the Accuracy of Fisheries Data used for Assessment (WKACCU, ICES, 2008). The workshop developed a practical framework for detecting potential sources of bias in fisheries data collection programs. A scorecard was applied to indicators of bias for a suite of parameters that are important for stock assessments. The scorecard can be used to evaluate the quality of data sources used for stock assessments, and to reduce bias in future data collections by identifying steps in the data collection process that must be improved.

WKACCU SCORECARD	NO BIAS	POTENTIAL BIAS	CONFIRMED BIAS	COMMENT
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff		1		Potential for mis-identification of *Nephrops* burrows on UWTV footage. Accounted for in relative to absolute correction factor, but requires knowledge of ecosystem and other burrowing fauna.
2. Species misreporting	1			
3. Taxonomic change	1			
4. Grouping statistics	1			
5. Identification Key	1			
Final indicator				
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part	1			
2. Area misreporting	1			
3. Quantity misreporting	1			
4. Population of vessels	1			
5. Source of information	1			
6. Conversion factor	1			

WKACCU SCORECARD	No bias	Potential bias	Confirmed bias	Comment
7. Percentage of mixed in the landings	1			
8. Damaged fish landed	1			
Final indicator				
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification				
1. Sampling allocation scheme		1		Not all fisheries sampled for discarding.
2. Raising variable	1			
3. Size of the catch effect	1			
4. Damaged fish discarded	1			
5. Non response rate	1			
6. Temporal coverage	1			
7. Spatial coverage	1			
8. High grading	1			
9. Slipping behaviour	1			
10. Management measures leading to discarding behaviour	1			
11. Working conditions	1			
12. Species replacement	1			
Final indicator				
D. EFFORT				
Recall of bias indicator on species identification				
1. Unit definition				
2. Area misreporting	1			
3. Effort misreporting	1			

WKACCU scorecard	No bias	Potential bias	Confirmed bias	Comment
4. Source of information	1			
Final indicator	1			
E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol	1			
2. Temporal coverage	1			
3. Spatial coverage	1			
4. Random sampling of boxes/trips	1			
5. Availability of all the landings/discards	1			
6. Non sampled strata	1			
7. Raising to the trip	1			
8. Change in selectivity	1			
9. Sampled weight	1			
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				No age determination possible
1. Quality insurance protocol	0			
2. Conventional/actual age validity	0			
3. Calibration workshop	0			
4. International exchange	0			
5. International reference set	0			
6. Species/stock reading easiness and trained staff	0			

WKACCU SCORECARD	NO BIAS	POTENTIAL BIAS	CONFIRMED BIAS	COMMENT
7. Age reading method	0			
8. Statistical processing	0			
9. Temporal coverage	0			
10. Spatial coverage	0			
11. Plus group	0			
12. Incomplete ALK	0			
Final indicator	0			
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure	0.5			
1. Sampling protocol	1			
2. Temporal coverage	1			
3. Spatial coverage	1			
4. Statistical processing	1			
5. Calibration equipment	1			
6. Working conditions	1			
7. Conversion factor	1			
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure	0.5			
1. Sampling protocol	1			
2. Temporal coverage	1			
3. Spatial coverage	1			
4. Staff trained	1			
5.Size/maturity effect	1			

WKACCU SCORECARD	NO BIAS	POTENTIAL BIAS	CONFIRMED BIAS	COMMENT
6. Catchability effect	1			
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol	1			
2. Appropriate time period	1			
3. Spatial coverage	1			
4. Staff trained	1			
5. International reference set	1			
6. Size/maturity effect	1			
7. Histological reference	1			
8. Skipped spawning	1			
Final indicator	1			
Final indicator				

5 Overview of methodology

5.1 Classification of stocks according to ICES data categories

5.2 UWTV-surveys

Many *Nephrops* stocks use an underwater TV survey as the primary data source for stock assessment. This approach involves the analysis of video footage of the seabed from which counts of *Nephrops* burrows are made and the density of animals derived. This methodology is the focus of an ICES working group (WGNEPS) and the reports of this group detail the processes and standards expected for such a survey to be used for the determination of stock status.

5.3 Yield and biomass per recruit

At the first *Nephrops* benchmark (WKNEP 2009), two length-based cohort models (LCA) were presented and adopted as methods for estimating harvest ratios that could be considered appropriate proxies for fishing at F_{MSY}. Since then, these methods have been used to determine the Harvest Rates for all stocks for which there was an accepted UWTV survey surveys (FUs 3–4, 6, 7, 8, 9, 11, 12, 13, 14, 15, 17, 19, 20–21 and 22).

5.4 MSY proxy recommendations

Owing to the way *Nephrops* are assessed, it is not possible to estimate F_{MSY} directly and hence proxies for F_{MSY} are determined. WGNSSK (2010) developed a framework for proposing F_{MSY} proxies for the various *Nephrops* stocks based upon their biological and historical characteristics, and is described in Section 1 of that report. 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 in many stocks. To account for this, values for each of the candidates have been determined for males, females and the two sexes combined. An appropriate F_{MSY} candidate has been selected 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 (ICES, 2010a). These proxies may be modified following further data exploration and analysis. The combined sex F_{MSY} proxy should be considered appropriate if the resulting percentage of virgin spawner-per-recruit for males or females does not fall below 20%. When this does happen a more conservative sex-specific F_{MSY} proxy should be picked instead of the combined proxy.

Table 6.1. Standard FU harvest rate rationale table used by WGNSSK and WGCSE.

		Burrow density (average burrows m−2)		
		Low	Medium	High
		<0.3	0.3-0.8	>0.8
Observed harvest rate or landings compared to stock status	> FMAX	F35%SPR	FMAX	FMAX
	FMAX - F0.1	F0.1	F35%SPR	FMAX
	< F0.1	F0.1	F0.1	F35%SPR
	Unknown	F0.1	F35%SPR	F35%SPR
Stock size estimates	Variable	F0.1	F0.1	F35%
	STable	F0.1	F35%SPR	FMAX
Knowledge of biological parameters	Poor	F0.1	F0.1	F35%SPR
	Good	F35%SPR	F35%SPR	FMAX
Fishery history	STable spatially and temporally	F35%SPR	F35%SPR	FMAX
	Sporadic	F0.1	F0.1	F35%SPR
	Developing	F0.1	F35%SPR	F35%SPR

5.5 Stocks without TV-surveys

Using FU area (calculated from information on the extension of suitable habitat and/or extent of *Nephrops* fisheries), mean discard percentage from all years of data, and mean weight in catches, tables of harvest ratios were calculated for each of the five data-poor functional units, using a range of landings (100 t to maximum landings observed for each stock) and densities (0.05–0.8 animals m-2). The density range come from the North Sea/Skagerrak stocks for which UWTV surveys exist. For each data-poor FU, the mean and maximum of the landings time-series is marked in the table. Harvest ratios larger than 10% are marked red. For each stock the most likely densities are considered based on information from neighbouring FUs.

This approach enables the working group to consider the sustainability of historic landings as well as present a guidance to landings within safe biological limits.

5.5.1 North Sea (FU 32) category 3 or 4 procedure

The FU 32 stock is classified as a category 4 stock (stocks for which only reliable catch data are available) (ICES, 2016). A stock biomass index was developed for the 2016 benchmark, based on *Nephrops* data from the annual Norwegian shrimp survey which covers FU 32 at depths greater than 100 m (see Section 8.7.2 and Annex 2). A stock for which survey-based assessments indicate trends is a category 3 stock. The benchmark was, however, reluctant to accept the survey index as a valid biomass index for the stock in FU 32, basically due to the scarce *Nephrops* data from the shrimp survey. The stock will therefore remain as a category 4 stock, but the survey index will be included as an indicator in the advice together with the Danish lpue and length frequencies in catches.

5.6 Alternative approaches

5.6.1 Analytic assessments

A non-equilibrium hierarchical method of estimating fishing and natural mortality for *Nephrops* was presented to the group. This hierarchical model uses time series data of mean length and effort for multiple functional units and provides stock- and sex-specific estimates of both F and M. Traditionally *Nephrops* natural mortality has been assumed to be 0.2 or 0.3. However, the hierarchical mean length and effort model challenged that assumption and estimated natural mortalities that varied widely by stock, ranging from 0.14 – 0.70 for males and 0.08 – 0.51 for females. This model was applied to *Nephrops* FUs 3–4, 23–24, 28–29, 30, and 31. For details about model theory, formulation, results, and diagnostics, see Annex 2, working paper 1.

5.7 Alternative approach to setting reference points in cases of high model uncertainty

The group considered approaches to take where there was a large disparity between the surveys and different model estimates of population size and/or exploitation rate. This was particularly pertinent for FU 23-24 and FU30 where the low harvest rate implied by UWTV stock size and the landings is at odds with the relatively high fishing mortality rate suggested by the length frequency (i.e. a lack of large individuals in the landings). Applying the MSY harvest rates estimated by the LCA models to the stock abundance estimated by the UWTV survey would result in landings (and hence harvest rates) several times higher than recent extractions. In cases where there is consistent scientific evidence that such large extraction rates are not inconsistent with MSY principles then naturally ICES advice should reflect such increases in extractions. Where there are opposing signals in the analyses which cannot be resolved then there is no scientifically credible basis on which any advice for such large increases in extraction rates can be made and a more pragmatic approach to phased increases (whilst monitoring stock response) might seem appropriate.

The group therefore considered what might be appropriate intermediate extraction rates based upon the history of the affected FUs and the performance of other *Nephrops* fisheries. The range of observed Harvest Rates were compiled for all stocks currently assessed with UWTV surveys and these are in the text table below. A number of stocks are regularly fished well in excess of their target harvest rates (FU 6, 8, 13). Almost all stocks are fished above their MSY target rates at some point, only FUs 7 and 14 are fished regularly within the MSY rate and these give maximum harvest rates of ~10%. From those stocks with accepted reference points, $F_{0.1}$ also corresponds to a harvest rate of around 10% and all stocks have tolerated harvest rates at this level over a number of years. The benchmark group did not find anything wrong with the UWTV estimates, and thought that even though the Y/R calculation gave sensible values of $F_{0.1}$ (at least in line with the HR for other stocks), there were too many concerns to justify recommending such drastic increases in catches in one step. Accordingly, a staged increase from current HRs was recommended with monitoring of the reaction of the stocks to the increased exploitation before further increases. In order to help guide the creation of a transition process, the historical experience of the FU as well as other FUs with similar stock densities (and other characteristics) should be considered.

Table 6.2. Observed Harvest Rates, MSY proxies and F0.1 estimates for other FUs outside this benchmark.

Fmsy proxy	FU	Min observed HR	Mean observed HR	Max observed HR	Fmsy HR	F0.1
F01 comb	7	2%	6%	10%	8%	8%
	14	6%	7%	7%	11%	11%
	19	4%	8%	11%	8%	8%
F35 comb	9	6%	14%	20%	12%	8%
	11	6%	12%	19%	11%	8%
	12	6%	13%	27%	12%	9%
	22	5%	12%	24%	11%	8%
F35 male	6	6%	16%	25%	8%	9%
Fmax comb	8	16%	22%	29%	16%	9%
	13	16%	25%	52%	16%	*
	15	13%	18%	22%	17%	*

***Not given in stock assessment report or stock annexes.**

6 *Nephrops* in FU 3 and 4

6.1 Multispecies and mixed fisheries issues

Cod and sole are significant bycatch species in these fisheries in 3.a, and even if data on catches, including discards, of the bycatch gradually become available, they have not yet been used in the management. The WG has for many years recommended the use of species selective grids in the fisheries targeting *Nephrops* as legislated for Swedish national waters. New technical measures (Swedish grid and SELTRA trawl) have recently been agreed upon for the *Nephrops* directed fishery and have been implemented since the 1st February 2013. The European Union and Norway have also agreed that a discard ban will be implemented in EU waters from the 1st January 2015. The discard ban will be applicable to *Nephrops* from the 1st January 2016 but preliminary results indicating high discard survival has resulted in an exception of landing obligation for *Nephrops* in 3.a during 2016.

6.2 Impacts of the fishery on the ecosystem

6.3 Ecosystem drivers

Nephrops live in burrows in suitable muddy sediments and is characterised by being omnivorous and emerge out of the burrows to feed. It can, however, also sustain itself as a suspension feeder in the burrows (Loo *et al*., 1993). This ability may contribute to maintaining a high production of this species in 3.a, due to increased organic production. *Nephrops* have recently been found to have a high prevalence of plastics which may have implications for the health of the stock (Murry and Cowie, 2011).

Severe depletion in oxygen content in the water can force the animals out of their burrows, thus temporarily increasing the trawl catchability of this species during such environmental changes (Bagge *et al*., 1979). An especially severe case was observed in the end of the 1980s in the southern part of 3.a in late summer, where unusually high catch rates of *Nephrops* were observed. The increasing amount of dead specimens in the catches led to the conclusion of severe oxygen deficiency in especially the southern part of 3.a (Kattegat) in late 1988 (Bagge *et al*., 1990).

No information is available on the extent to which larval mixing occurs between *Nephrops* stocks, but the similarity in stock indicator trends between FU 3 and 4 for both Denmark and Sweden indicates that recruitment has been similar in both areas. These observations suggest they may be related to environmental influences.

6.4 Stock identity, distribution and migration issues

At present there are two functional units in Division 3.a: Skagerrak (FU 3) and Kattegat (FU 4). This separation was based on observed differences between Skagerrak and Kattegat regarding *Nephrops* size composition in catches in the 1980s and 1990s. However, the distribution of *Nephrops* is almost continuous from southern Kattegat into Skagerrak, and the exchange of pelagic larvae between the southern and northern areas is very likely. With the longer dataseries now available, it seems the differences in size composition between the two areas are more likely to be random or caused by factors from fishing operations. The assessment is therefore conducted on *Nephrops* in 3.a as one stock.

6.5 Influence of the fishery on the stock dynamic

Not explored at this benchmark.

6.6 Influence of environmental drivers on the stock dynamic

Not explored at this benchmark.

6.7 Stock assessment data and information

6.7.1 Catch and landings data-quality, misreporting, discards, selection at-length

Landings

Division 3.a includes FU 3 and 4, which are assessed together. Total *Nephrops* landings by FU and country are shown in Tables 3.2.1.1 and 3.2.1.2.

FU 3 is primarily exploited by Denmark, Sweden and Norway. Denmark and Sweden dominate this fishery, with 58% and 38% by weight of the landings in 2015, respectively. Landings by the Swedish creel fishery represented 13–18% of the total Swedish *Nephrops* landings from the Skagerrak in the period 1991 to 2002. Since 2002 creel catches have been steadily increasing and have in 2009 to 2014 accounted for more than 30%, and in 2015 for more than 40% of Swedish Skagerrak landings (Table 3.2.2.1). In the early 1980s, total *Nephrops* landings from the Skagerrak increased from around 1000 t to just over 2670 t. Since then they have been fluctuating around a mean of 2500 t (Figure 3.2.2.1).

Both Denmark and Sweden have *Nephrops* directed fisheries in the FU 4 (Kattegat). In 2015, Denmark accounted for about 73% of total landings in FU4, while Sweden took 27% (Table 3.2.2.5). Minor landings have been taken by Germany (<1%).

After a decline in the observed landings in 1994, total *Nephrops* landings from the Kattegat increased again until 1998 and have fluctuated around 1500 t. However, since 2006 the landings have increased and were in 2010 the highest on record over the 50 year period (Figure 3.2.2.4). Since 2010, landings show a decreasing trend.

Catch and effort data-FU3

Effort data for the Swedish fleet are available from logbooks for 1978–2015 (Figure 3.2.2.1 and Table 3.2.2.2). During the period 1998 to 2005, twin trawlers shifted to targeting both fish and *Nephrops*, which resulted in a decreasing trend in lpue during this period (Table 3.2.2.2). Since 2005, lpue for twin trawls has increased. The lpue for single trawls has shown and increasing trend throughout the entire time-series. The long-term trend in lpues is similar in the Swedish and Danish fisheries (Figure 3.2.2.1). Total Swedish trawl effort shows a decreasing trend since 1992 and has been fluctuating without trend since 2003. From 2007 onwards, total Swedish trawl effort has been estimated from lpues from the single trawl with a grid (targeting only *Nephrops*).

Danish effort figures for the Skagerrak (Table 3.2.2.3 and Figure 3.2.2.1) were estimated from logbook data. For the whole period, it is assumed that effort is exerted mainly by vessels using twin trawls. The overall trend in effort for the Danish fleet is similar to that in the Swedish fishery. After having been at a relatively low level in 1994–1998, effort increased again in the next four years, followed by a decrease to a relatively low level in 2007 to 2015. Also the trend in lpue is similar to that in the Swedish single trawl fishery, however with a much more marked increase in the Danish lpue for 2007 and 2008. This high lpue level is likely to be a consequence of the national (Danish) management system introduced in 2007.

It has not been possible to explicitly incorporate 'technological creeping' in a further evaluation of the Danish effort data. However, since 2000 the Danish logbook data have been analysed in various ways to elucidate the effect of factors likely to influence the effort/lpue, e.g. vessel size (Figure 3.2.2.3).

Norwegian catch and effort data are available from electronic logbooks from 2011. Logbooks previous to 2011 had in some years a very low coverage of the landings. The electronic logbooks have been compulsory for all vessels ≥12 m in Skagerrak since 2013 (compulsory for all vessels ≥15 m in 2011–2012). As the Norwegian shrimp/*Nephrops* fleet in Skagerrak consists of many small vessels (<15 m), the electronic logbooks in 2011–2012 similarly had a very low coverage of the trawl landings (2–3%) (Table 7.7.1). The data situation has improved since 2013, with 40–60% of the trawl landings covered by logbooks. As mesh size was not given in the 2011–2012 logbooks, it was not possible to filter out data from hauls with *Nephrops* trawls (70–90 mm mesh size) for these two years.

Table 7.7.1. Norwegian logbooks from Skagerrak (FU 3): Number of vessels and hauls, per trawl gear and year. Trawl landings (tons), logbook catches from trawls (tons), and percentage coverage of trawl landings by logbooks, per year. 2016 data until August.

	SHRIMP TRAWL		LARGE MESH TRAWL		*NEPHROPS* TRAWL				
	hauls	vessels	hauls	vessels	hauls	vessels	LANDINGS	LOGBOOK CATCHES	% IN LOGBOOKS
2011	462	12	10	2			74	1.9	2.6
2012	397	13	2	2			80	1.4	1.8
2013	666	21	17	4	231	5	57	21.2	37.2
2014	594	24	10	3	476	6	68	32.5	47.8
2015	567	23	25	8	465	8	66	40	60.6
2016	529	23	14	3	264	7			

The lpue index from shrimp trawls increased from 2012 to 2013 (Figure 7.7.1). Closer inspections of the logbook data revealed that the catch rates of *Nephrops* in shrimp trawls increase from west to east in Skagerrak, with the highest catch rates close to the Swedish border. The number of logbook recordings from this area increased in 2013 when logbooks became compulsory also for vessels between 12 and 15 m (Figure 8.5.1). This probably explains the increased catch rate in 2013. *Nephrops* trawls are in use mostly in the easternmost part of Skagerrak (Figure 8.5.1). The Norwegian lpue index from *Nephrops* trawls is on the same level as the Swedish one (Figure 7.7.2).

In lack of better data for *Nephrops* along the Norwegian Skagerrak coast, the benchmark recommends to present and update the Norwegian lpue indices from shrimp and *Nephrops* trawls as part of the annual assessment of the FU 3 stock.

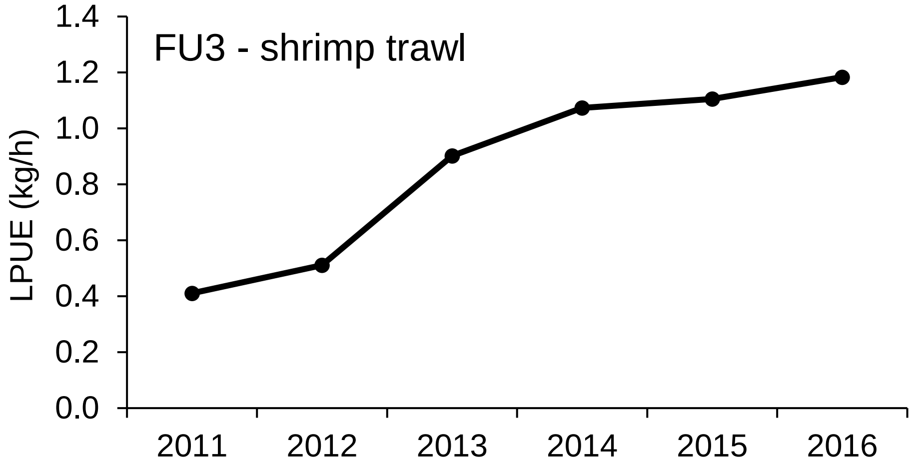

Figure 7.7.1. Lpue (kg/h) of *Nephrops* taken as bycatch in Norwegian shrimp trawls (mesh size between 35 and 60 mm) in Skagerrak (FU 3).

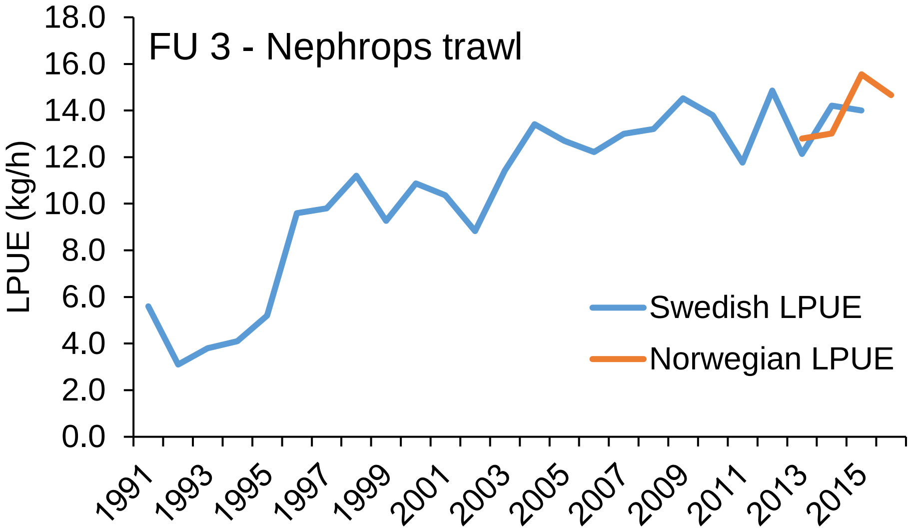

Figure 7.7.2. Lpue (kg/h) of *Nephrops* from *Nephrops* trawls (mesh size between 70 and 90 mm) in the Norwegian and Swedish fisheries in Skagerrak (FU 3).

Catch and effort data–FU4

Swedish total effort has been relatively stable over the period 1978–1990. Effort increased from 1990 to 1993, followed by a decrease to 1996. During the last 20 years effort has remained relatively stable, except for 2007 and 2008 where effort increased (Figures 3.2.2.4 and Table 3.2.2.6). Figures for total Danish effort are based on logbook records since 1987. Danish effort increased from 1995 to 2001, decreased from 2002 to 2007 and has been fluctuating without trend since (Figure 3.2.2.4 and Table 3.2.2.7).

Since 2000 the Danish logbook data have been standardised to account for changes in fishing power due to changes in the physical characters of the *Nephrops* fleet. The data have been analysed in various ways to elucidate the effect of factors likely to influence the effort/lpue, e.g. vessel size (Figure 3.2.2.6).

6.7.2 Survey data

The assessment of the state of the *Nephrops* stock in 3.a is based on the UWTV survey from 2015. Additional used information was trends in total combined (Denmark and Sweden) lpue, and discards (numbers) as a proxy for recruitment during the period 1990–2015.

6.7.3 Biological data-weights, maturities, growth, natural mortality

In previous analytical assessments (when Length Cohort Analyses were performed, see e.g. WGNEPH, 2003), natural mortality was assumed to be 0.3 for males of all ages and in all years. Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females. Discard survival was assumed to be 0.25 for both males and females (after Gueguen and Charuau, 1975; Redant and Polet, 1994 and Wileman *et al*., 1999).

Growth parameters are as follows:

Males: $L\infty$ = 73 mm CL, k = 0.138.

Immature females: $L\infty$ = 73 mm CL, k = 0.138.

Mature females: $L\infty$ = 65 mm CL, k = 0.10, Size at 50% maturity = 29 mm CL.

Growth parameters for males were taken from Ulmestrand and Eggert (2001) and female growth parameters have been assumed to be similar to those of Scottish *Nephrops* stocks.

Data on size-at-maturity for males and females were presented at the ICES Workshop on *Nephrops* Stocks in January 2006 (ICES WKNEPH, 2006).

6.7.4 Commercial dataseries

6.7.5 Stakeholder data

6.7.6 Environmental data

6.7.7 Other indicators-length distributions, etc.

Length compositions

For the Skagerrak, size distributions of both the landings and discards are available from both Denmark and Sweden for 1991–2015. In the beginning of the time-series, the Swedish data can be considered as being the most complete, since sampling took place regularly throughout the time period and usually covered the whole year. Trends in mean size in catch and landings for Skagerrak are shown in Figure 3.2.2.2 and Table 3.2.2.4. Mean sizes for landings are fluctuating without trend. Mean size for undersized show an increasing trend since 2005.

For Kattegat, size distributions of both the landings and discards are available from Sweden for 1990–2015, and from Denmark for 1992–2015. The at-sea-sampling intensity has generally increased since 1999. The Danish sampling intensity was low in 2007 and 2008, but was normalized in 2009 to 2015. Information on mean size is shown in Figure 3.2.2.5 and Table 3.2.2.8. Notice, that except for small mean sizes from 1993 to 1996 all categories have since been fluctuating without trend.

In earlier years, the Swedish discard samples were obtained by agreement with selected fishermen, and this might have tempted fishermen to bias the samples. However, the reliability of the catch samplings was cross-checked by special discard sampling projects in both the Skagerrak and the Kattegat. In recent years, the Swedish *Nephrops* sampling has been carried out by on-board observers in both Skagerrak and Kattegat. In 1991, a biological sampling programme of the Danish *Nephrops* fishery was started on board fishing vessels in order to also cover the discards in this fishery. Due to its high cost and the lack of manpower, Danish sampling intensity in the early years was in general not satisfactory, and seasonal variations were not often adequately covered. The Norwegian *Nephrops* fishery is small and has not been sampled.

6.8 Stock assessment model

In 2008 and 2009, an exploratory UWTV survey was carried out by Denmark. In 2010, the TV survey was expanded covering the main *Nephrops* grounds in the western part of Skagerrak (Subarea 1) and Northern part of Kattegat (Subarea 2). Since 2011, the TV survey has been carried out in collaboration between Denmark and Sweden and covers the main *Nephrops* fishing grounds in 3.a (Subarea 1–6). In 2014, Subarea 1 was extended to the west (Subarea 7; Figure 3.2.3.2). A similar survey design has been applied for both national surveys: a fixed grid with random stratified stations.

In order to estimate the total population numbers, the density estimates have to be raised from the survey areas to total area of the population distribution. VMS information is currently the best available proxy to estimate the *Nephrops* stock distribution in 3.a. VMS data from the Swedish and Danish fishery from 2010 were used (Figure 3.2.3.3) and are described in more detail in ICES (2011). The area estimates for each subarea are defined in Table 3.2.3.1. Burrow counting and identification follows the standard protocols defined by WGNEPS (ICES, 2013).

6.9 Short-term projections

6.9.1 Input data

6.9.2 Model and software, how Y/R and SSB are derived

6.10 Reference points

There are no precautionary reference points defined for *Nephrops*. Under the ICES MSY framework, exploitation rates which are likely to generate high long-term yields (and low probability of stock overfishing) have been explored and proposed for Division 3.a. Owing to the way *Nephrops* are assessed, it is not possible to estimate F_{MSY} directly and hence proxies for F_{MSY} are determined. WGNSSK (2010) developed a framework for proposing F_{MSY} proxies for the various *Nephrops* stocks based upon their biological and historical characteristics, and is described in Section 1 of that report. 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 in many stocks. To account for this, values for each of the candidates have been determined for males, females and the two sexes combined. An appropriate F_{MSY} candidate has been selected 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 (ICES, 2010a). These proxies may be modified following further data exploration and analysis. The combined sex F_{MSY} proxy should be considered appropriate if the resulting percentage of virgin spawner-per-recruit for males or females does not fall below 20%. When this does happen a more conservative sex-specific F_{MSY} proxy should be picked instead of the combined proxy.

		Burrow density (average burrows m−2)		
		Low	Medium	High
		<0.3	0.3-0.8	>0.8
Observed harvest rate or landings compared to stock status	> Fmax	F35%SPR	Fmax	Fmax
	Fmax - F0.1	F0.1	F35%SPR	Fmax
	< F0.1	F0.1	F0.1	F35%SPR
	Unknown	F0.1	F35%SPR	F35%SPR
Stock size estimates	Variable	F0.1	F0.1	F35%
	Stable	F0.1	F35%SPR	Fmax
Knowledge of biological parameters	Poor	F0.1	F0.1	F35%SPR
	Good	F35%SPR	F35%SPR	Fmax
Fishery history	Stable spatially and temporally	F35%SPR	F35%SPR	Fmax
	Sporadic	F0.1	F0.1	F35%SPR
	Developing	F0.1	F35%SPR	F35%SPR

The absolute burrow density in Division 3.a is medium (0.3–0.8/m²), the observed harvest rate is below $F_{0.1}$ and historically the fishery is stable both spatially and temporally. This means that $F_{0.1}$ may be selected as a proxy for F_{MSY}. As the MLS has been decreased in 2016 and this stock will be benchmarked during 2016, it is recommended to use F_{MAX} as a proxy for F_{MSY} as in last years. For 2017 this corresponds to a TAC of 13 099 tonnes if a landing obligation is applied. Under a landings obligation it may well be necessary to recalculate a harvest rate associated with F_{MSY} as total catches would be subjected to 100% mortality (current discard survival is estimated to be 25%).

6.10.1 Reasoning behind the reference point values

6.10.2 Recommended exploitation level

6.11 References

6.12 Future research and data requirements

7 *Nephrops* in FU 32

7.1 Multispecies and mixed fisheries issues

7.1.1 Trophic interactions

Not considered in the present benchmark.

7.1.2 Fishery interactions

Trawl catches of *Nephrops* in FU 32 are bycatches from the mixed fishery (120 mm mesh size) and the shrimp fishery. There is no directed trawl fishery for *Nephrops* in this functional unit (mesh sizes of 70–90 mm have not been allowed in Norwegian waters of the North Sea since 2004).

Bycatches of *Nephrops* from the Norwegian shrimp fishery have declined as the shrimp fishery has declined. The shrimp stock has declined and contracted into the southern part of the functional unit. The mixed fisheries have declined as well, but the reasons for this are less clear. The Norwegian mixed fishery in FU 32, where *Nephrops* is taken as bycatch, has for all practical purposes ceased to exist (Figure 8.5.1).

7.2 Impacts of the fishery on the ecosystem

Not considered in the present benchmark.

7.3 Ecosystem drivers

Not considered in the present benchmark.

7.4 Stock identity, distribution and migration issues

As part of the Interreg-project ØBJ-FISK (2012–2014), the genetic stock structure of *Nephrops* in the Kattegat-Skagerrak-Norwegian Deep area was investigated using microsatellites. Two fjords were sampled in addition to the FUs 3, 4, and 32: the Hardangerfjord and Gullmarsfjord. Samples from Scotland and Iceland were included as outgroups. The study did not find any significant genetic structure within the Kattegat-Skagerrak-Norwegian Deep area (Frandsen *et al*., 2015; Westgaard *et al*., in prep.). However, due to the different fisheries and fishing effort, as well as the different monitoring effort in FU 32 vs FUs 3 and 4, it is recommended to continue keeping these areas as separate management units.

The Interreg-results showed evidence of sex-related genetic differences with males being more differentiated than females, thus indicating female biased dispersal.

7.5 Influence of the fishery on the stock dynamic

The Danish and Norwegian trawl fisheries are now concentrated in the southern part of the functional unit and along the Norwegian coast (Figures 8.5.1, 8.5.2). A declining Danish in the last years (Figure 8.7.2.1) may indicate a high fishing pressure in the area where the fishing takes place (ICES, 2016) (but see below). The Norwegian commercial fishery has turned into a coastal trap fishery (ICES, 2016; Søvik *et al*., accepted), which, together with a growing, but unknown recreational coastal pot fishery, may have a negative effect on *Nephrops* stock(s) along the Norwegian coast and in fjords.

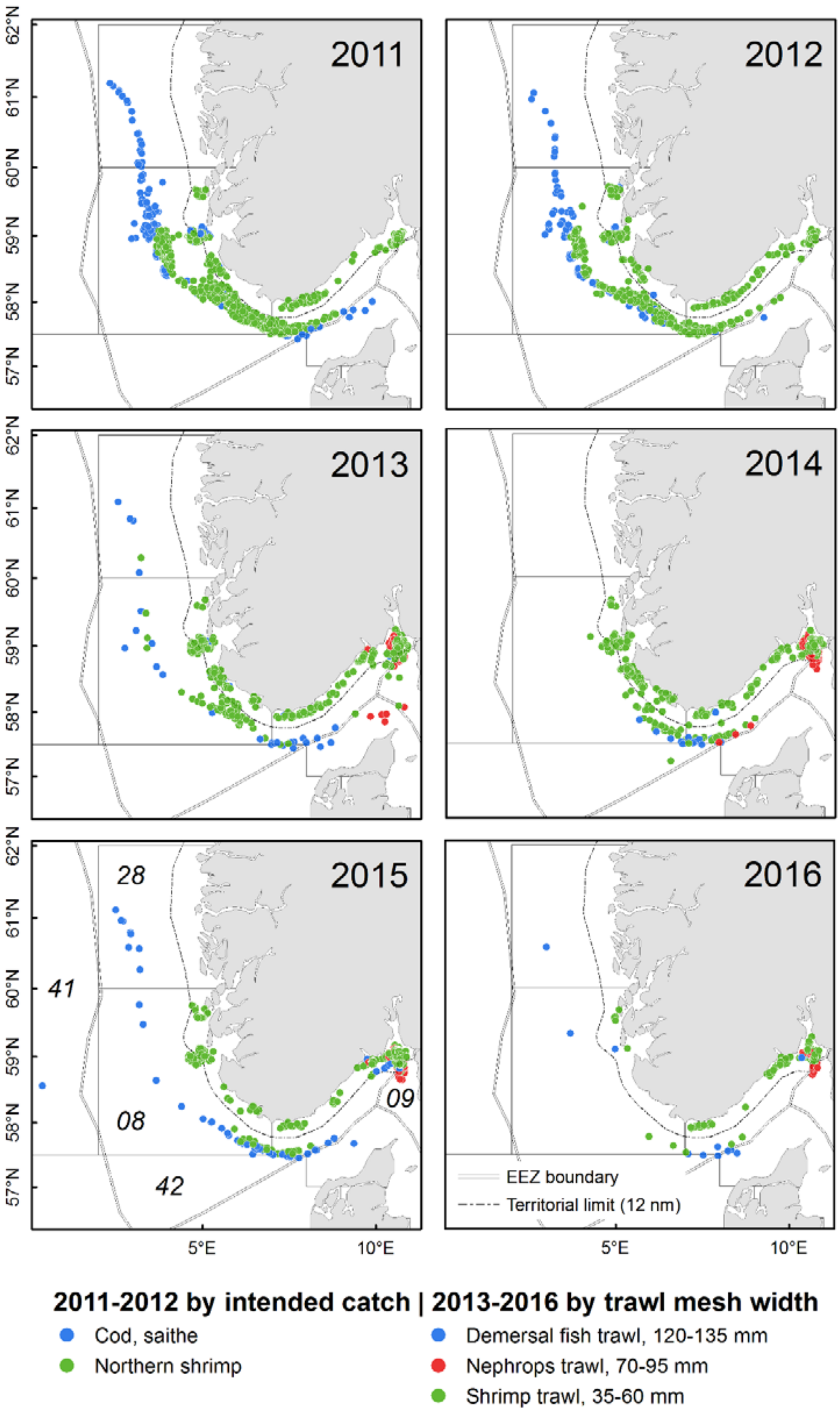

Figure 8.5.1. ***Nephrops*** **in FU 32: Spatial distribution of the Norwegian large vessel (≥15 m)** ***Nephrops*** **trawl fishery, 2011–2016: Haul positions of catches with demersal and shrimp trawls containing** ***Nephrops*** **from Norwegian electronic logbooks. For the Skagerrak, the data also include vessels ≥12 m since 2013. The 2011–2012 data are filtered by "intended catch" (fish, shrimp) (mesh size information lacking); the 2013–2016 data are filtered by mesh size. The plot for 2016 is based on data from January–June. Data provided by the Norwegian Directorate of Fisheries.**

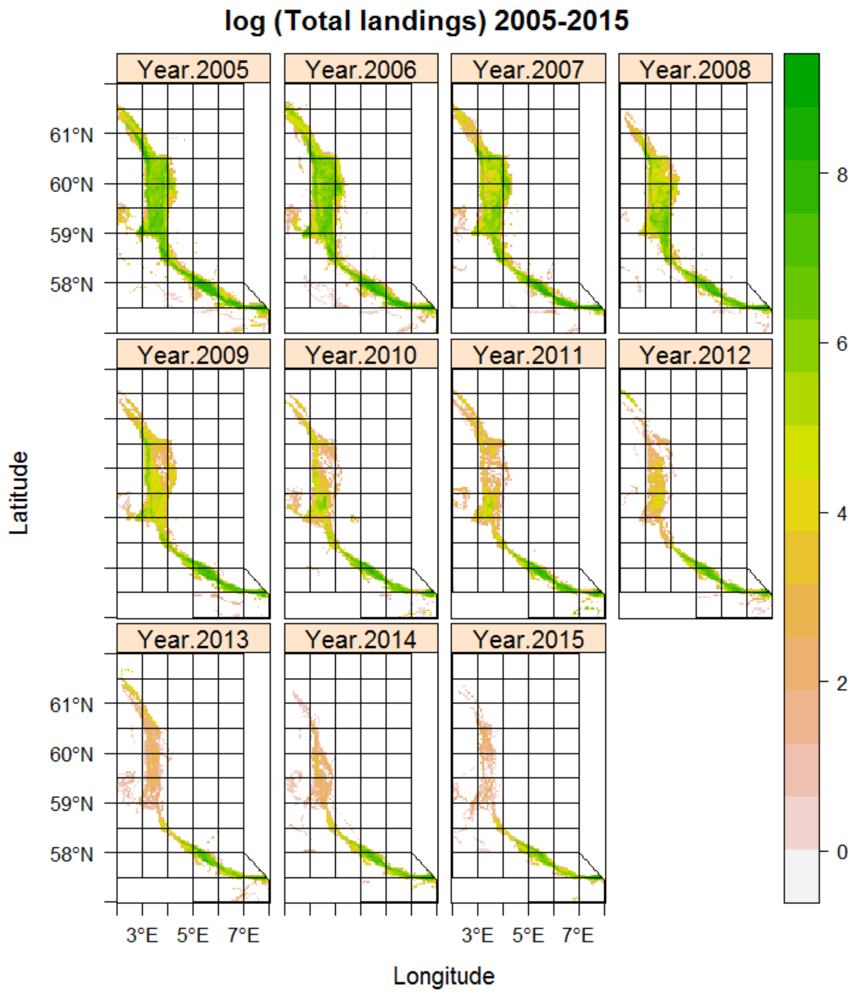

Figure 8.5.2. ***Nephrops*** **in FU 32: ln (total Danish landings from mixed fishery) for 2005–2015. Grid cells are approximately 3 by 3 km (geographic grid of 1 x 2 minutes). The area of FU 32 is redefined to conform to the updated border between Skagerrak and the Norwegian Deep, which follows the TAC of** ***Nephrops*** **within EU.**

7.6 Influence of environmental drivers on the stock dynamic

Not considered in the present benchmark.

7.7 Stock assessment data and information

7.7.1 Catch and landings data-quality, misreporting, discards, selection at-length

Not considered in the present benchmark.

7.7.2 Survey data

There has not been any fishery-independent stock size index available for *Nephrops* in FU 32. The annual Norwegian shrimp survey, which started in 1984, covers the whole of Skagerrak and Norwegian Deep. Catches of *Nephrops* in the Campelen trawl are small and highly variable both within and between years. The 2013 benchmark of the

FU 32 *Nephrops* still recommended closer investigation of these survey data in order to establish a fishery-independent stock size index (ICES, 2013).

Analyses of the 2006–2016 survey data were carried out and a working document produced for the present benchmark meeting (Annex 2, working paper 3). The biomass index had high values in 2006 and 2007 and then declined to a lower level in 2008. Thereafter the index has fluctuated without trend (Figure 8.7.2.1). The Danish lpue has similarly decreased since 2008–2009 (Figure 8.7.2.1). It should be noted that the survey index covers the whole Norwegian Deep area for depths >100 m, while the Danish lpue covers the western and southern part of the Norwegian Deep.

The new survey index is based on few observations (Annex 2, working paper 3). However, in lack of better data, the benchmark considers that the index should be presented and updated as part of the annual assessment procedure of the FU 32 stock.

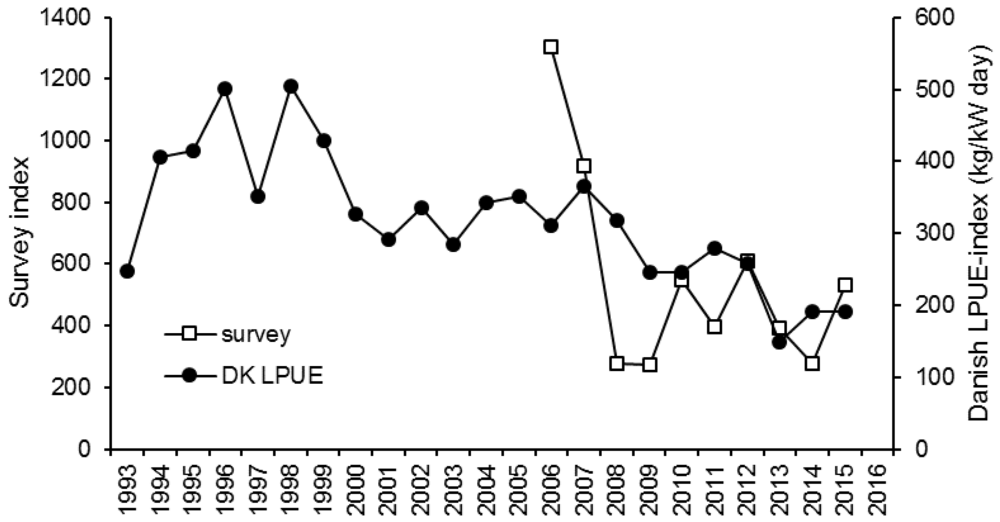

Figure 8.7.2.1. *Nephrops* in FU 32: A survey biomass index from the Norwegian annual shrimp survey in the Norwegian Deep and the Danish lpue (kg/kW day).

7.7.3 Biological data-weights, maturities, growth, natural mortality

Not considered in the present benchmark.

7.7.4 Commercial dataseries

Norwegian logbook data

The Norwegian logbook data from FU 32 were explored as part of the 2013 benchmark on *Nephrops* stocks (ICES, 2013). For several reasons it was concluded that data from the mixed fishery (mesh size ≥120 mm) were unsuitable for analyses. One vessel completely dominated the logbook data in the years 2003–2008. Catches from this vessel made up almost 100% of the logbook catches in 2003–2006 and 70–90% of the catches in 2007–2008. Strange recordings of haul duration by this vessel in 2005–2007 led to elevated lpue values.

The electronic logbooks (compulsory for all vessels ≥15 m), available from 2011, have a better resolution of the data compared with the old logbooks, with catches recorded by haul (prior to 2011, catches were recorded by day), and with information on haul positions 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. In 2011–2012, information on mesh size is lacking. Mesh size was reintroduced in 2013.

The Norwegian data situation in FU 32 has, however, not improved with the introduction of the electronic logbooks, basically because there are so few large Norwegian vessels landing *Nephrops* from this area (Table 8.7.4.1). Furthermore, one vessel has dominated the large mesh trawl fishery for several years. In 2015–2016, trawl landings comprised <10% of the Norwegian total *Nephrops* landings from FU 32 (ICES, 2016). The trap fishery is carried out by small vessels, which are not obliged to fill out logbooks. An lpue index based on the Norwegian electronic logbooks is thus not representative of the present Norwegian *Nephrops* fishery in FU 32.

Table 8.7.4.1. *Nephrops* in FU 32: Number of hauls and vessels in the electronic logbooks of the Norwegian shrimp and large mesh fisheries, 2011–2016. Data from the Norwegian Directorate of Fisheries.

	SHRIMP TRAWL		LARGE MESH TRAWL		
	Hauls	Vessels	Hauls	Hauls (vessel X)	Vessels
2011	594	21	162	145	7
2012	490	23	123	115	4
2013	249	14	59	12	7
2014	212	13	10	0	3
2015	159	11	43	4	6
2016*	75	12	28	18	4

*** data until August.**

Danish logbook data

The benchmark decided to use the present distribution of the Danish fishery to estimate a new area for the harvest rate table for FU 32. Danish *Nephrops* fishing grounds were identified using Danish VMS and logbook data (Figure 8.7.4.1). Data from the Danish mixed fishery (≥120 mm mesh size) were used, where daily *Nephrops* landings from logbooks were distributed evenly on the corresponding VMS signals, filtered by speed (2–4 knots). Spatial analysis was preformed using a geographic grid of the size of 1 x 2 minutes, and annual maps of total *Nephrops* landings and nominal effort were produced (Figures 8.7.4.2, 8.7.4.3). The data were further filtered for daily *Nephrops* ratios >0.05 in the landings. For each year, fishing ground, defined as the smallest number of grid cells containing 95% of the landings, was estimated (Figure 8.7.4.4). Both the union and the intersection of the areas for each year was calculated representing the maximum and minimum estimate of the fishing grounds. By shifting the starting year to use in the calculations, the spatial contraction of the utilized fishing ground was visualized; the fishery presently uses only approximately one third of the area used in the mid-2000s.

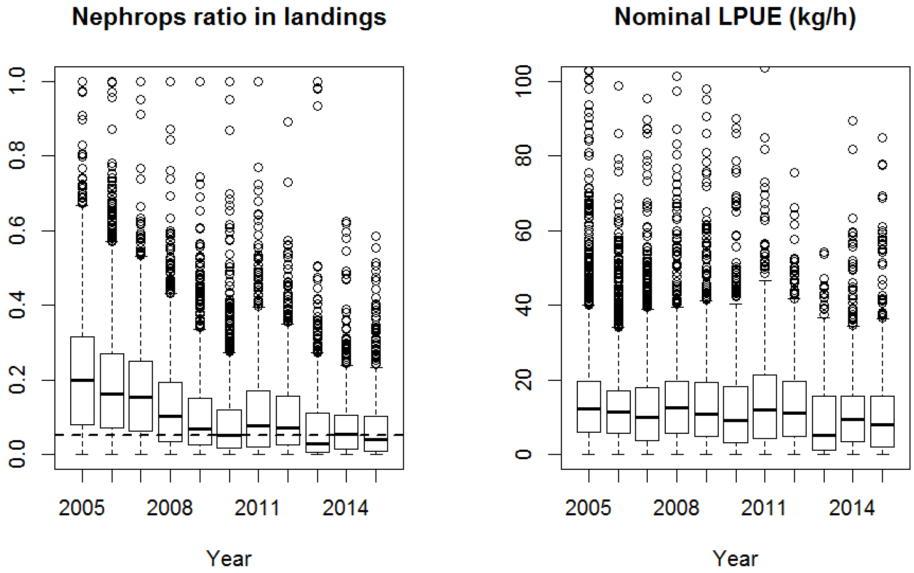

Figure 8.7.4.1. ***Nephrops*** **in FU 32:** ***Nephrops*** **ratio in Danish landings (left) and nominal lpue (kg/h) (right) per year, 2005–2015. The horizontal dashed line in left panel is the 0.05 ratio of** ***Nephrops*** **in the landings used as filter in the spatial analysis.**

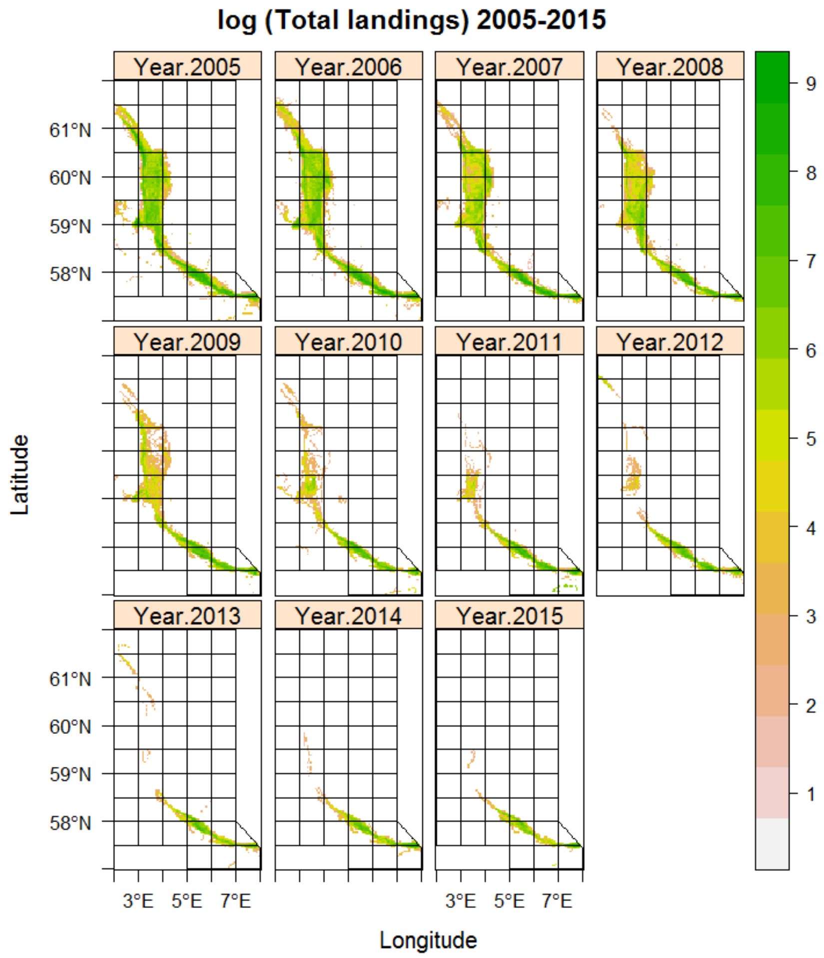

Figure 8.7.4.2. ***Nephrops*** **in FU 32: ln (total Danish landings from mixed fishery), where** ***Nephrops*** **ratio in landings >0.05 (compare with Figure 8.5.2 where all Danish landings are included). Grid cells are approximately 3 by 3 km (geographic grid of 1 x 2 minutes). The area of FU 32 is redefined to conform to the updated border between Skagerrak and the Norwegian Deep, which follows the TAC of** ***Nephrops*** **within EU.**

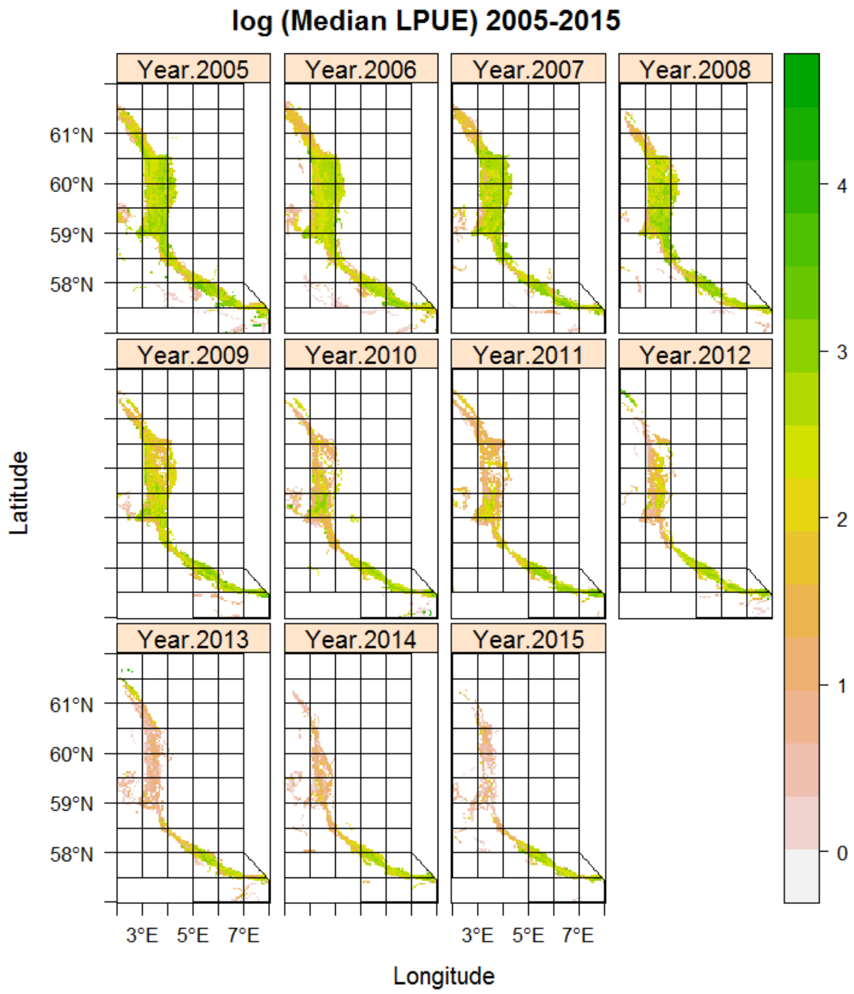

Figure 8.7.4.3. ***Nephrops*** **in FU 32: ln (median Danish nominal lpue + 1) for 2005–2015. Grid cells are approximately 3 by 3 km (geographic grid of 1 x 2 minutes). The area of FU 32 is redefined to conform to the updated border between Skagerrak and the Norwegian Deep, which follows the TAC of** ***Nephrops*** **within EU.**

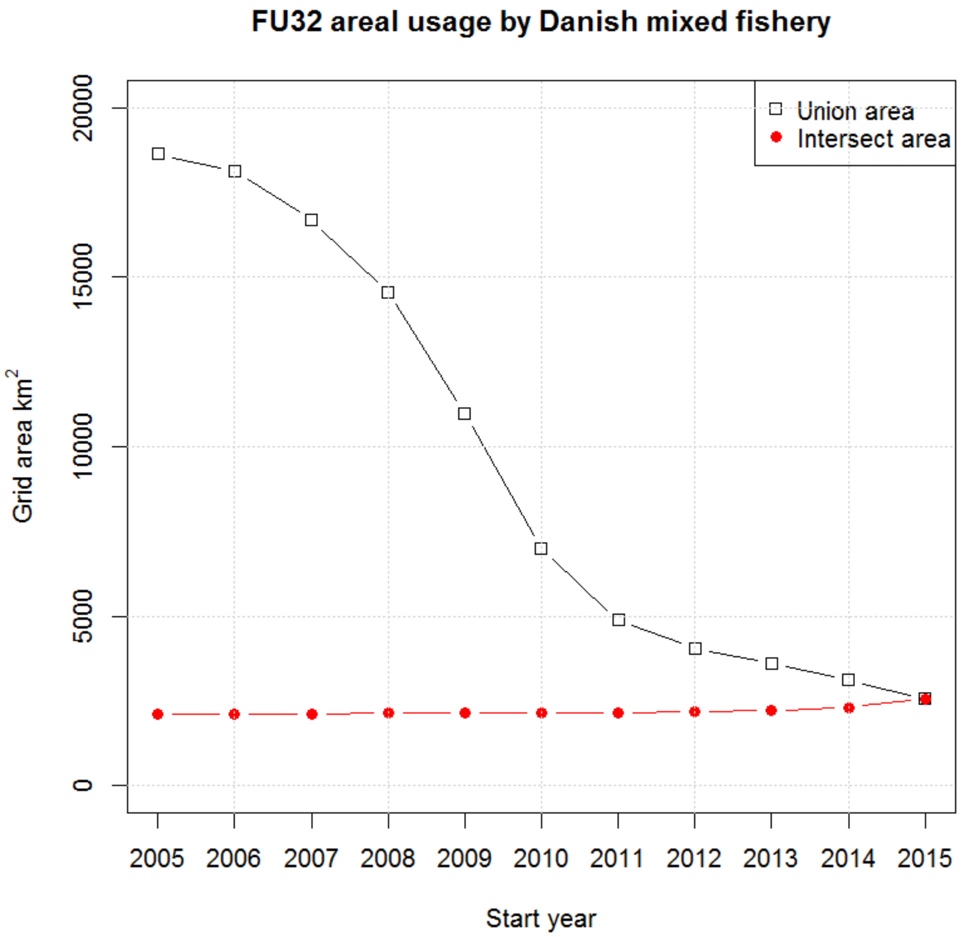

Figure 8.7.4.4. ***Nephrops*** **in FU 32: Union and intersection areas for Danish fishing grounds based on all years' data as a function of starting year. The grid cells with highest value summing to 95% of annual total Danish landings are used.**

The Danish catch rate has declined since 2007 and is presently at the lowest observed level in the time-series (Figure 8.7.2.1). At the same time, the fishery has contracted and since 2013 it has been located in the southernmost part of the functional unit. The low lpue observed in 2013–2015 may thus imply either that fishing pressure has increased in the southern part of FU 32 resulting in a decreased stock density, or that stock density has always been lower in the southern part of FU 32 compared with the northern part.

The Danish lpue in the southern part of FU 32 has decreased somewhat recently (Figure 8.7.4.3). However, first and foremost the catch rate has decreased substantially in the northern part of the functional unit, from the years 2005–2008 to the years 2013–2015. The only area with reasonably good catch rates at present is the southern part. It should, however, be taken into account that Figure 8.7.4.3 is based on nominal lpue, while an lpue index based on an effort series of kW days shows a much stronger decline in recent years (ICES, 2015). A decrease in catch rate is in accordance with the Norwegian survey data, which showed a decline in biomass from 2007 to 2008. It should be noted that in 2007 individual vessel quotas were introduced in the Danish fishery, which resulted in the vessels buying up a lot of fish quotas and shifting their effort to fin fish rather than *Nephrops* (ICES, 2016). This change in management coincided with the decreasing lpue (2008–2009) and the onset of steadily falling Danish *Nephrops* landings.

7.7.5 Stakeholder data

Not available for this stock.

7.7.6 Environmental data

Nephrops occurs south to Morocco, which suggests that it might tolerate increased sea temperatures in the northern part of its distribution range. The 1st quarter mean bottom temperature in FU 32 (from the annual Norwegian shrimp survey) varied between 6.6 and 7.9°C in the years 2006–2015. The temperature in 2016 was the warmest in the time-series going back to 2006, with a mean of 8.2°C. Salinity has varied between 35.15 and 35.26‰ in the time period 2006–2016.

7.7.7 Other indicators–length distributions, etc.

Length distributions are available from the Danish fishery, and from sampling by the Norwegian Coast Guard of both Norwegian and Danish vessels (mainly recordings of total length). These data were not reanalysed as part of the present benchmark.

7.8 Stock assessment model

Not available for this stock.

7.9 Short-term projections

Not available for this stock.

7.9.1 Input data

7.9.2 Model and software, how Y/R and SSB are derived

7.10 Reference points

Not available for this stock.

7.10.1 Reasoning behind the reference point values

7.10.2 Recommended exploitation level

7.11 Other issues–Catch advice based on harvest rate table

Following the procedure for data-poor *Nephrops* stocks, an estimated guidance of the biomass in FU 32 is provided allowing different harvest rates to be calculated (see Stock Annex). Using FU area, mean density of *Nephrops*, mean discard percentage, and mean weight in Danish landings and discards, a table of harvest rates (HR) is calculated using a range of catches.

Previously, the discard percentage from the last ten years was used, together with mean weight in Danish landings and discards from the most recent year. To standardize procedures across data-poor *Nephrops* stocks in the North Sea, mean values from the last three years will hereafter be used. A minimum density of 0.1 animals per square meter from the neighbouring functional unit Fladen Ground is used as a mean density of *Nephrops* in FU 32. The fishery has now contracted into the southern part of FU 32 and is located closer to the *Nephrops* fishery in Skagerrak than to the fishery on Fladen Ground. There are only two years of density estimates from Subarea 7 in Skagerrak (the westernmost subarea). The density in 2014 was 0.284 animals per square meter and in 2015 it was 0.224. A density of 0.2 animals per square meter from FU 3 (Subarea 7) will be indicated in the HR table.

The total area of *Nephrops* grounds in FU 32 has previously been estimated using information on the geographic distribution of the Norwegian and Danish fisheries, as well as suitable sediment (55 500 km^2). With the fishery being contracted in the southern part of FU 32, the value of 55 500 km^2 gives unrealistically low harvest rates. The Danish logbook data were therefore reanalysed as part of the present benchmark, and the present distribution of the Danish fishery is used to provide a new area estimate (Table 8.11.1). The extent of the Norwegian trawling grounds is not included in the new area estimate as the Norwegian trawl fishery is now very small.

As the Danish fishery is now contracted in the southern part of FU 32, the benchmark decided to use the 2013 value of 3613 km^2 as a new area estimate for the HR table.

Table 8.11.1. *Nephrops* in FU 32: Area estimates (km^2) of Danish fishing grounds, union of the areas (maximum estimate), based on the smallest number of grid cells containing 95% of the landings. The 2005 value is the union of the set of all grid cells common to the years 2005–2015. The 2004 value is the union of the set of all grid cells common to the years 2004–2015, etc.

YEAR	AREA_UNION (KM^2)
2005	18 624
2006	18 126
2007	16 673
2008	14 557
2009	10 973
2010	7001
2011	4886
2012	4052
2013	3613
2014	3115
2015	2559

7.12 References

Frandsen, R., Eliasen, S.Q., Lövgren, J., Søvik, G., Feekings, J.P., Ulmestrand, M., Lund, H., Andersen, B.S., Axelsen, B.E., Bastardie, F., Berg, C.W., Bichel, N., Furevik, D., Jacobsen, J.B., Johansen, T., Jonasdottir, S., Jonsson, P., Jørgensen, T., Karlsen, J.D., Kleiven, A.R., Løkkeborg, S., Lundgren, B., Madsen, N., Munch-Petersen, S., Nielsen, A., Nielsen, J.R., Reeh, L., and Westgaard, J-I. 2015. Sustainable development of the *Nephrops* fishery in the Kattegat-Skagerrak region. DTU Aqua report no. 298–2015, 212 pp.

ICES. 2013. Report of the Benchmark Workshop on *Nephrops* Stocks (WK*NEPH*) 25 February–1 March 2013, Lysekil, Sweden. ICES CM 2013/ACOM:45. 230 pp.

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ICES. 2016. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) 26 April–5 May 2016, Hamburg, Germany. ICES CM 2016/ACOM: 14. 1023 pp.

Søvik, G., Furevik, D., Jørgensen, T., Bakke, S, Larssen, W.E., Thangstad, T.H. and Woll, A.K. 2016. The Norwegian *Nephrops* fishery - history, exploitation and management. (book chapter, Møreforskning, accepted).

7.13 Future research and data requirements

The recent shift of the Norwegian fishery from trawls to traps means that we know very little about the present Norwegian *Nephrops* fishery in FU 32. It is recommended to initiate data collection (catch rate, length and sex data) from commercial trap fishers (a reference fleet) to monitor this fishery.

8 *Nephrops* in FU 23–24

8.1 Multispecies and mixed fisheries issues

8.1.1 Trophic interactions

Nephrops are scavengers as well as a predator, meaning the forage for food as well as actively prey on food items (Johnson *et al.*, 2013). Typical food items of wild *Nephrops* include echinoderms, crustaceans, polychaetes as well as some fish (Johnson *et al.*, 2013). The most common prey items found in the stomach of *Nephrops* are amphipods, ostracods and other decapod species, some of which can be nearly the same size as the *Nephrops* (Bell *et al.*, 2013). In addition to the feeding styles already mentioned *Nephrops* also feed on plankton which they extract from the water column by filter feeding (Johnson *et al.*, 2013). *Nephrops* can also be considered cannibalistic with individual feeding on conspecifics (Welden *et al.*, 2015).

Cod (*Gadus morhua*) is a natural predator of *Nephrops*, feeding on both adult and juvenile *Nephrops*. Research has indicating that 88% of *Nephrops* predation is as a result of cod (Bell *et al.*, 2013). An investigation conducted in Scottish waters examining the stomachs from cod found that up to 80% of the cod population contained *Nephrops* within their stomachs. For this reason it is also important to understand the trophic relationships of *Nephrops* as overfishing and exploitation cannot only result in population crashes of this species but also influence populations of non-target species (Armstrong, 1982).

In the Irish Sea other predators of *Nephrops* have also been found to include pouting (*Trisopterus luscus*) and poor cod (*Trisopterus minutus*) (Armstrong, 1982). Whilst in Scottish waters species that have also been observed predating on *Nephrops* include lesser spotted dogfish (*Scyliorhinus canicula*) and the thornback ray (*Raja clavata*) (Armstrong, 1982).

Limited information is currently available on *Nephrops* predators in lower latitudes, however it is suggested that other large fish species will probably will replace the role of cod within those specific foodwebs (Bell *et al.*, 2013).

In the Bay of Biscay it was advanced that large sized hakes could be predators of *Nephrops* whereas the undersized ones are their competitors for feeding. Nevertheless, no significant dataset can confirm this suggestion for predation.

8.1.2 Fishery interactions

The main fishery interaction for the FU23–24 *Nephrops* involves in the role of the Central Mud Bank as a substantial nursery for the northern hake stock. This interaction was studied and modelled under different management scenarii (Drouineau *et al.*, 2006). For a long period both species were targeted in this mixed fishery whereas hake became unwanted catch for *Nephrops* trawlers during the more recent years. Management plans have been established to protect hake in this area mainly since the recovery plan for the species in the mid-2000s (hake box for mesh size not less than 100 mm, square panel for hake). In spite of those regulations, hake discarding remains high.

8.2 Impacts of the fishery on the ecosystem

Recent analysis carried out by sedimentologists emphasized that the intensive action of specifically targeting *Nephrops* trawls has significant impact on the fine sedimentary configuration of the sea bottom (Bourillet *et al.*, 2006). The surface of the traditional compact mud bottom seems to be reduced and gradually replaced by less muddy sediments similar to the outer edge of the central mud bank. This depletion may induce effect on carrying capacities for *Nephrops* burrowing (the size of burrows depends on the compactness of the sediment).

The trawling activities on *Nephrops* cause very high discard rate on species such as the northern hake and seasonally the blue whiting and the horse mackerel.

8.3 Stock identity, distribution and migration issues

Nephrops are distributed in Northeast Atlantic, from Iceland to South Portugal. It is not common in the Mediterranean Sea except in the Adriatic Sea, notably the North Adriatic and it is absent from both the Black Sea and the Baltic Sea. *Nephrops* live on 15–800 m deep grounds, on muddy substrata. The distribution of this species is more determined by ground type and sea temperature than depth. *Nephrops* live in burrows dug in the mud. It leaves this burrow during low light periods (at dawn and dusk) to look for food. It can be caught in high quantities during this active time. *Nephrops* are sedentary. However they can move short distances if adverse factors modify its habitat, like mud disturbance by storms or other mechanical action on the sea bottom.

The studied area called "Central Mud Bank" was described by Dubrulle *et al.* (2005), Bourillet *et al.* (2006) and it extends for 11 676 km² of surface if only the typical muddy strata are taken into account whereas more recent studies (UWTV surveys; see below) suggest to incorporate in the whole area some rough sea grounds crossed by muddy channels and also included in the external outline of the Central Mud Bank (surface increasing up to 16 164 km²). The specific aspects of its ecosystem were analysed by Le Loc'h (2004). Around 100 m of depth, generally comprised in the range 70–120 m, this area is wide up to 150 km in the Northern part and it is shrunk (~25 km) in the Southern limits. The muddy layer formed in the 2nd ice period is generally thin (0.5–1.5 m) apart from the extreme Northern part (3 m). The overall outline is fixed according to information of previous sedimentology studies combined with information linked to commercial fishing activity (e.g. VMS).

Five sedimentary strata vs. the mud composition of the sediment and its origin are defined (Figure 9.3.1):

1)	>25% mud	(abbreviation VV)
2)	>75% mud	(abbreviation VS)
3)	Lithoclastic mud<25%	(abbreviation LI)
4)	Carbonate mud<25%	(abbreviation CB)
5)	Calcareous mud<25%	(abbreviation CL)

The surface involving in *Nephrops* is precisely delimited owing two information: (1) on the sedimentary structure of the sea bottom (five spatial strata; Figure 9.4.1 above); (2) on the systematic grid of video tracks combined with VMS data for the fishery (Figure 9.4.1 below; data source: National Fisheries Direction; compilation: Ifremer). Sampling of landings and discards (on-board and at auction) has provided yearly dataset since

1987 and mainly since 2003 owing to the monitoring of the European DCF plan (Table 9.5.1; Figure 9.5.1).

8.4 Influence of the fishery on the stock dynamic

The main fishery in the FU23–24 *Nephrops* area is the mixed one *Nephrops*/hake. As mentioned above (Section 9.1.2), many management regulations were decided in the early 2000s in order to preserve juvenile in this hake nursery as there was a recovery plan. Fishing industry underlined that the protection of the Northern hake stock may have negative effect on the *Nephrops* abundance. The small hake individuals are competitors of *Nephrops* but there is not enough information on the potential predation of large hake individuals against *Nephrops*, thus this opinion is not scientifically demonstrated.

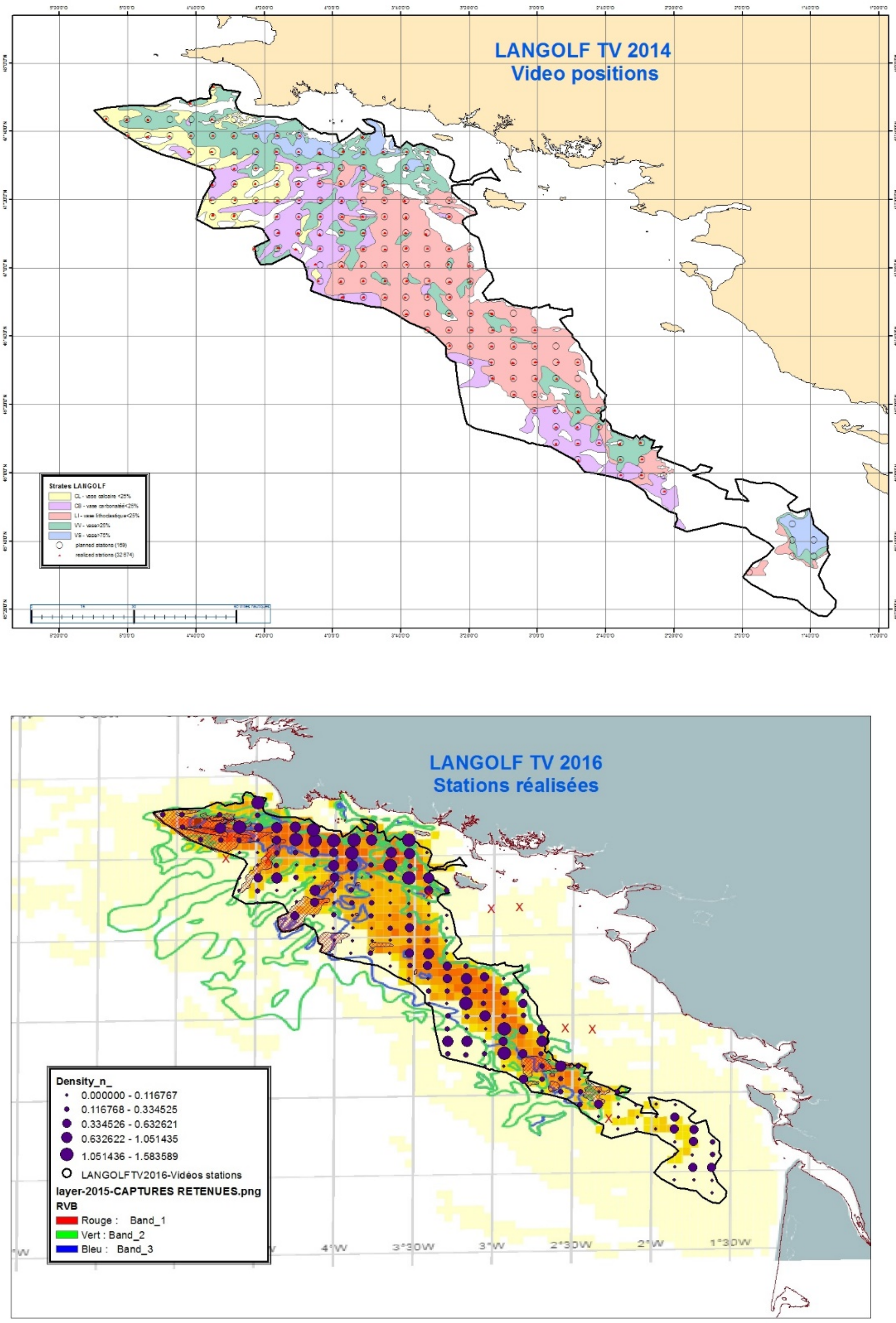

Figure 9.4.1. Above: spatial stratification of the Bay of Biscay according to sedimentary criteria (see details Section 9.3). Below: UWTV stations on a systematic grid (example of the year 2016) and VMS data for retained catches of *Nephrops* (example of the year 2015; source: National Fisheries Direction; compilation: SIH Ifremer).

8.5 Influence of environmental drivers on the stock dynamic

Some coastal areas of the central muddy bank in the Bay of Biscay are periodically used by gravel extraction operations, but there is no currently significant operation. Moreover, it should be intended that the entire stock area is included in Commission OSPAR scheme (Protected Marine Areas) implying impact on trawling activities although this project is currently delayed.

Table 9.5.1. *Nephrops* in the Bay of Biscay (8.ab). Above: Landed and discarded weights. Below: Discards and landings in numbers (10^3 individuals) obtained by sampling on board and at auction. CVs (%) for landings and discards by sex. Example from years 2014 and 2015. No stratified estimates (left column by sex) or stratified on a quarterly basis (right column by sex).

	Landings (1)					Total Discards		Catches
Year	FU 23-24 (2)	FU 23	FU 24	Unallocated (MA N)(3)	Total VIIIa,b	FU 23-24		Total
	VIIIa,b	VIIIa	VIIIb		used by WG	VIIIa,b		VIIIa,b
2003	1	3564	322	49	3886	1977	*	5863
2004	na	3223	348	5	3571	1932	*	5503
2005	na	3619	372	na	3991	2698	*	6689
2006	na	3026	420	na	3447	4544	*	7990
2007	na	2881	292	na	3176	2411	*	5587
2008	na	2774	256	na	3030	2123	*	5154
2009	na	2816	212	na	2987	1833	*	4820
2010	na	3153	245	na	3398	1275	*	4673
2011	na	3240	319	na	3559	1263	*	4822
2012	na	2290	230	na	2520	1013	*	3533
2013	na	2195	185	na	2380	1521	*	3900
2014	na	2699	108	na	2807	1326	*	4133
2015	na	3425	144	na	3569	1492	*	5061

YEAR	DISCARDS	LANDINGS	% DISCARDING
1987	268 244	288 974	48
1991	151 634	217 338	41
1998	150 995	161 549	48
2003	201 841	152 485	57
2004	222 089	139 753	61
2005	315 346	166 165	65
2006	487 288	127 942	79
2007	214 788	117 273	65
2008	198 031	115 274	63
2009	174 480	123 504	59
2010	113 530	138 120	45
2011	121 603	108 011	53
2012	117 935	101 424	54
2013	154 914	114 853	57
2014	117 930	121 594	49
2015	156 400[5]	138 921	53[6]

[5] Provisional estimation (of the WGBIE 2016 upwards revised: 156 400 thousands individuals discarded instead of 128 712).

[6] 53% of discard rate (instead of 48%) after the upwards revision for discards.

		males		females	
2014	LAN	21.53	13.36	22.72	19.03
	DIS	29.87	28.42	35.63	34.97
2015	LAN	13.53	10.78	14.42	14.34
	DIS	16.85	15.91	15.89	15.89

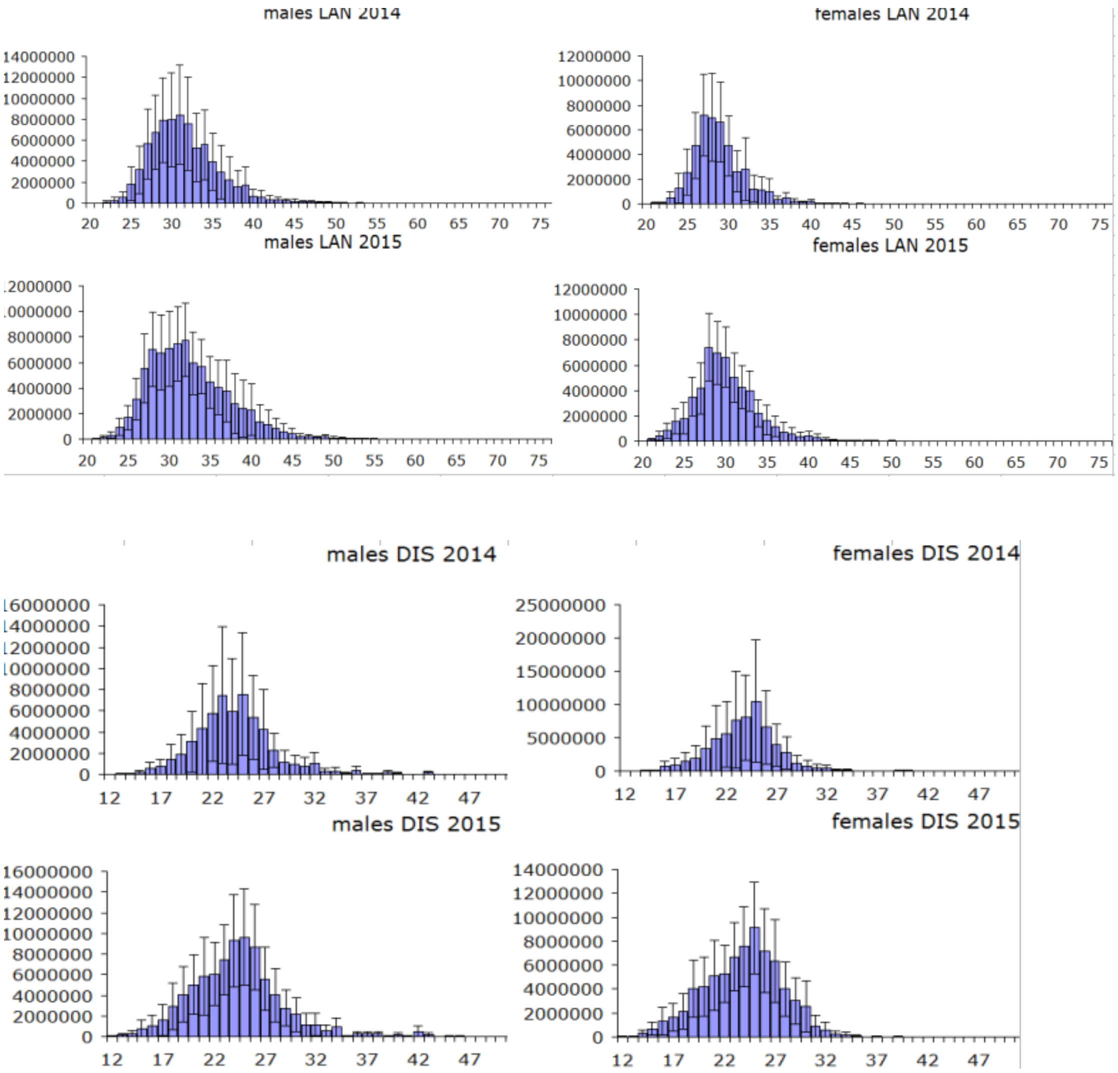

Figure 9.5.1. LFDs for yearly landings (above) and discards (below) by sex. Numbers of individuals vs. carapace length, mm and CVs by size. Years 2014 and 2015.

8.6 Stock assessment data and information

8.6.1 Catch and landings data-quality, misreporting, discards, selection at length

Landings

Throughout the mid-1960s, the French landings gradually increased to a peak value of 7000 t in 1973–1974, then fluctuated between 4500 and 6000 t during the 1980s and the mid-1990s. An increase has been noticeable during the early 2000s. Landings remained stable between 2008 and 2009 (3030 t and 2987 t) whereas they had decreased compared with previous years (3176 in 2007, 3447 t in 2006 and 3991 t in 2005). In 2010 and 2011, total landings increased (3398 t and 3559 t respectively), but in 2012 and 2013 a strong reduction of the landings occurred (2520 t and 2380 t respectively). In 2014, landings had increased significantly (2807 t: +18%), moreover steeply in 2015 (3569 t; +27%). Landings since 2008 have been reached under the new selectivity regulations.

Males predominate in the landings (sex ratio of 31–47% during the overall time-series 1987–2015). In the early 2000s the proportion of females in the landings slightly increased although the sex ratio in landings sloped down in recent years (since 2008) and reached the minimum level in 2011: that should be the consequence of the MLS change (1st December 2005) and, moreover, of the new selectivity regulations (1st April 2008) approving the increase of the caught fraction of males because of their higher growth.

Nearly all the landings from FUs 23–24 are taken by French trawlers apart from a minor part for Spanish vessels in the Management Area MA N although outside 8.abde. Misreporting or under-reporting does not seem to be a problem for the stock.

French sampling plan at auction started in 1984, but only from 1987 onwards can the data be used on a quarterly basis. Since 2003, additional database of landings was also provided by sampling routinely performed onboard under the European DCF (Data Collection Framework) aiming for discard estimates.

Discards

Discard data acquired by sampling on board are available for 1987, 1991, 1998 and since 2003. For recent years, discards have been estimated from sampling catches programme on board *Nephrops* trawlers (522 trips and 1513 hauls have been sampled over the period 2003–2015).

The overall programme is based on a stratified random sampling. Discards are estimated for each sampled fishing trip and raised by multiplying by the total number of fishing trip in the stratum. The total number of trips is usually not known, its estimate can be done using the number of auction hall sales in the case of trips of short duration (one day); that is the case for "Le Guilvinec" district, but not for the Southern part of the fishery.

Discards for sampled fishing trips are estimated by ratio estimator using the total landings as auxiliary variable (Talidec *et al.*, 2005) although for recent years under the new selectivity devices adopted since April 2008 the total landings do not seem to substantially improve the accuracy for the estimates. Discard sampling from the southern part of the fishery was carried out only once up to the middle of 2000s, but it has been routinely sampled since 2009, thus the sampling plan is better balanced among subareas and harbours. However, the total CVs for landings and discards are not fairly stable from year to year either if the quarterly stratification for estimates is retained or not (Figure 9.5.1; Table 9.5.1).

The average weight of discards per year on the period 1987–2002 (before DCF; only three years were sampled on board as explained above) was about 1550 t whereas discards since 2003 have reached a higher level (1950 t).

The data quality has been considered satisfactory since the yearly carried out DCF plan. Additionally, the spatial coverage was improved for recent years by a higher sampling rate for the fleet operating in the Southern part of the fishery which is more multipurpose than the Northern one.

For intermediate years up to 2002 with no sampling on board, numbers discarded at-length were derived in the following way: (1) the estimates for 1987–1990 from the data collected during the 1987 discard sampling programme; (2) those for 1991–1996 from the 1991 sampling programme; and (3) those for 1997, 1999–2003 from the 1998 sampling programme.

The derivation method uses ratios at each length between discards and total numbers landed for the two sexes combined.

Applying discard data from 'sampled' to 'non-sampled' years bears the risk of inconsistency between the different datasets because it induces an inter-dependence between years and also prevents detection of any signal on recruitment strength. Hence, WG investigated additional exploratory runs based on different approaches of derivation of discards for missing years.

In order to eliminate dependence between years due to derivation of missing years from common datasets, WGHMM since 2007 had carried out additional runs based on logistic derivation (*i.e.* simulation of the hand-sorting of marketable sizes) of discard length frequencies from those of landings year by year as regards to densities of probability. This method was adopted by IBP *Nephrops* 2012.

8.6.2 Survey data

Former trawl survey

The trawl survey conducted on years 2006–2013 provided global estimated relative indices and LFDs by sex associated to CVs. After the IBP *Nephrops* 2012, this series was included in the stock assessment for years 2012–2014 (intermediate year 2013 with no advice as the Bay of Biscay *Nephrops* stock was biennially advised under category 3).

Current UWTV survey (see also Stock Annex FU23-24)

The UWTV survey named "LANGOLF-TV" conducted since 2014 aimed to demonstrate the technical feasibility of such a survey in the local context and to identify the necessary competences and equipment for its sustainability. During the first two years, 2014 and 2015, video sampling was associated to a trawl one for the purpose of providing *Nephrops* LFDs by sex and estimating the proportion of other burrowing crustaceans (mainly *Munida*) which can induce bias in the burrows counting.

The assessment method based on UWTV data requires an unbiased and accurate calculation of the actual surface of the stock and, moreover, available dataset linked to the population dynamics (LFDs by sex for landings and discards). Both criteria are satisfied in the Bay of Biscay (see Section 9.4 and 9.7.1).

In 2014 and 2015, LANGOLF-TV was carried out on ten actual days associated to experimental trawling stopped thereafter whereas in 2016 the UWTV survey took place during 12 days. For each year six scientists participated on the on-board work. As the project was planned owing to a partnership with the "Marine Institute" (Republic of Ireland) one expert scientist and one electronics technician from Ireland joined the team.

Table 9.6.1. The LANGOLF-TV surveys 2014–2016.

YEAR	VESSEL+ACTUAL DURATION	DATES
2014	Celtic Voyager (10 days)	20–29/09
2015	Prince Madog (10 days)	20–29/07
2016	Celtic Voyager (12 days)	04–15/05

For the three surveys, the equipment (sledge, computing hardware, screens, recorders) were provided by the "Marine Institute". The sledge is based on the Scottish material (2.5 m*2.7 m*2.5 m; weight=80 kg); its speed is around 20 m/min.

In conformity with the recommendations of the SGNEPS (Anon, 2010) any new reader has to attend a training course in order to recognize the *Nephrops* burrows by avoiding possible confusions with other burrowing crustaceans structures. The main features for that are described during the WKNEPHTV in 2007 (Anon, 2007).

After this preliminary stage, a reading test on ten videos of 5 minutes is carried out. The provisional absence of reference footage in the Bay of Biscay implies the use of other support coming from grounds with similar conditions (density of burrows) to the Bay of Biscay: the Smalls grounds (FU22, Celtic Sea, UWTV surveyed since 2006) was chosen. A validation by the test CCC (Figure 9.6.2.3) allows to decide on the conformity or not of each reader.

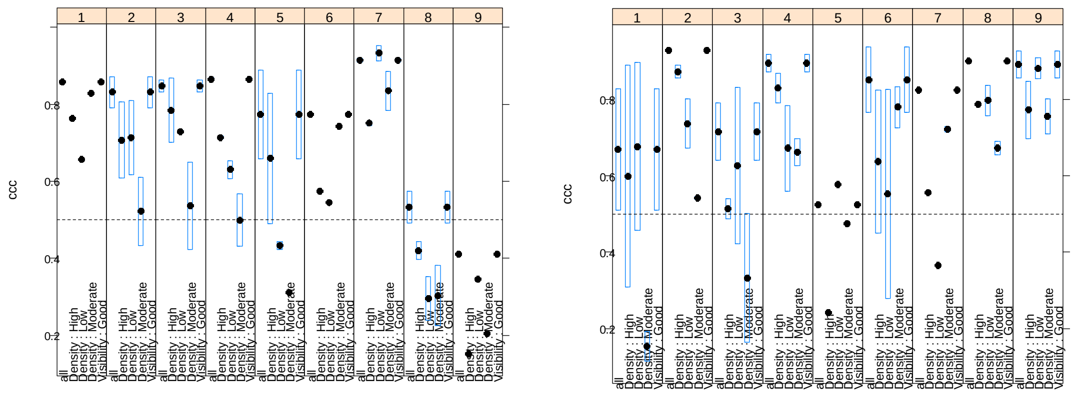

Figure 9.6.1. Conformity test CCC (reference footage: Smalls ground, FU22). Left: year 2014. Right: year 2015.

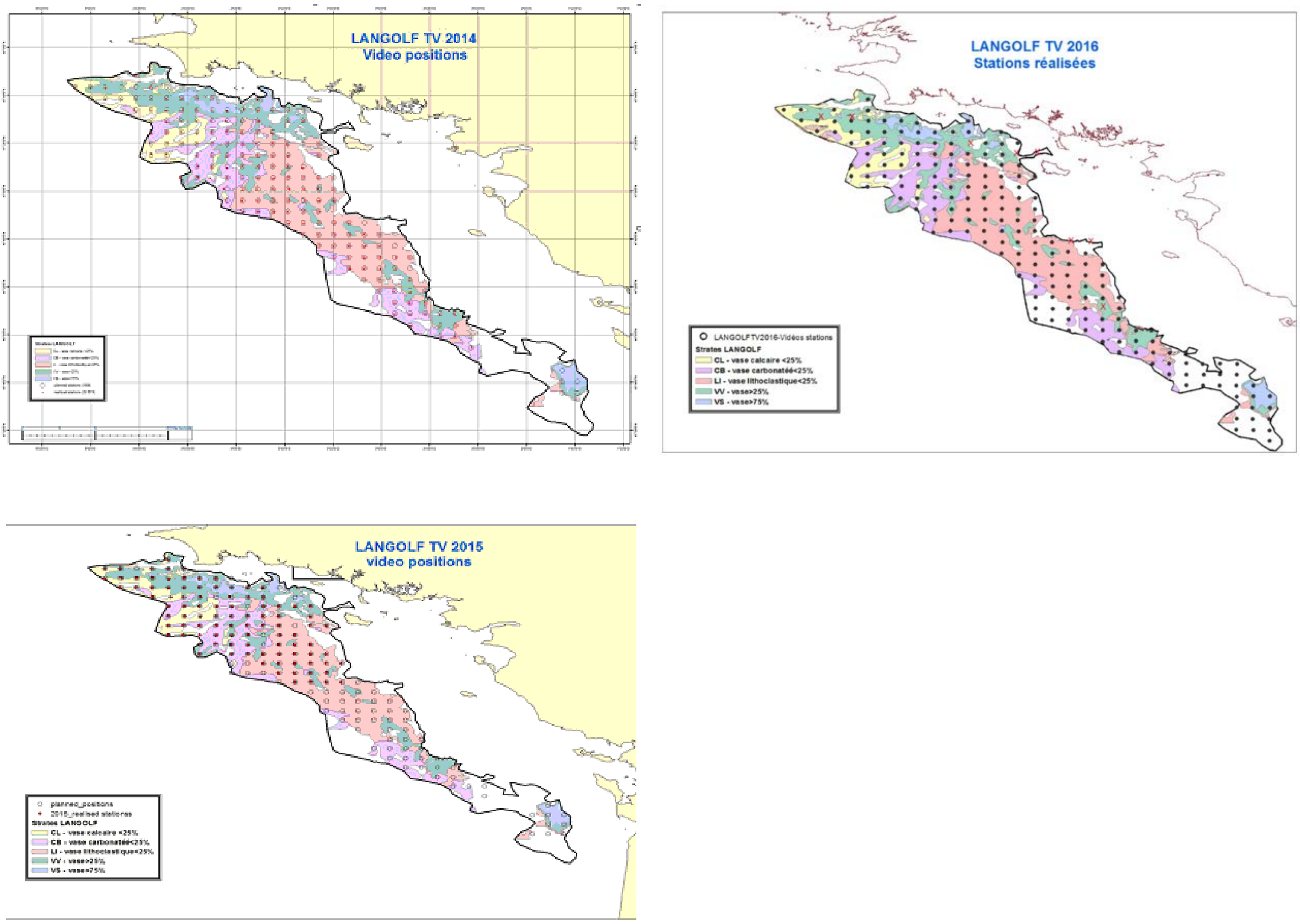

Figure 9.6.2. UWTV stations in the Bay of Biscay. Years 2014–2016.

Acquiring images on the sea bottom requires a preliminary use of multibeam sounder aiming to determine the nature of the sediment and to avoid technical problems due to rough ground. The recording starts when the sledge reaches the adequate speed (~0.8 knots), the contact with the sediment is conform and the visibility is satisfactory. Recording lasts 10 minutes even with no *Nephrops* burrows on the track; 7 minutes minimum are necessary for the validation of the footage.

In accordance with other routinely UWTV surveyed stocks (Anon, 2009), the sampling protocol applied since 2014 has been a systematic one advantaged by wider spatialised explorations on collected data. A distance of 4.7 nautical miles was retained similarly to the FU22 Smalls Ground. 165 stations were planned per year: among them 156 were validated for 2014 (few tracks abandoned due to rough sea bottom) whereas for 2015 96 stations were sampled because of bad meteorological conditions (Figure 9.6.2.4). The problem was tackled in 2016 by a longer survey duration: 14 effective working days were planned and owing to favourable conditions twelve days were sufficient to complete the whole grid (204 stations carried out among them 196 validated). Moreover, this enabling context allowed to cover for the first time the area contained in the outline of the Central Mud Bank no belonging to any sedimentary stratum: this area known as not trawled due to rough sea bottom was sampled by 36 validated stations completing the 160 stations of the five strata.

Statistical explorations were carried out either by stratified estimated vs. sediment or by geostatistics. Details are provided by Annex2 working documents 4 and 5. The Annex2 working document 5 investigates interactions *Nephrops* and *Munida* which may affect species identification factor due to a certain capacity of the second species to temporarily colonise *Nephrops* burrows.

For the major part of routinely UWTV surveyed *Nephrops* stocks data are processed by geostatistics at the purpose of distinguishing the spatial structures and proposing map interface tools. Many stocks (e.g. Western Irish Sea, Smalls in Celtic Sea) are very homogeneous and variography provides unbiased results.

Nevertheless, for heterogeneous areas needing spatial sedimentary stratification such as the Bay of Biscay the optimum situation should be to cross geostatistics tools with the sedimentary structure as co-variable. For the stability and the precision of fitted variograms for all strata, it should be necessary to have high video track numbers on some reduced surfaces (such as the stratum VS) corresponding to high density levels. As a reminder, for years 2014–2016, 50% of burrows are concentrated on 28% of the total surface (strata VS, VV). Alternative medium-term possibility should be to fit multi-annual variograms for the different types of sediment. In the current transition stage, investigations on the two statistical approaches are suitable additionally because of the spatial variability of some correction factors.

8.6.3 Biological data-weights, maturities, growth, natural mortality

Maturity

Males are sexually mature when they are about 6.5 cm long (20 mm CL) and two years old, females when they are about 7.5 cm long (22.4 mm CL; Jegou, 2007). Incubation takes seven months in the Bay of Biscay. Egg numbers increase according to size (a 7–8 cm long female has a mean egg number around 650, a 9 cm long 800 eggs, a 15 cm long 4000 eggs). The functional maturity for males occurs around 26 mm CL (Jegou, 2007).

Maturity for females is estimated on the basis of a yearly conducted on-board sampling design since 2004 owing to the DCF plan. The first years' dataset (2004–2006) allowed to slightly revise the maturity ogive for females (L50 of 22.43 mm CL instead of 25 mm CL previously used: see Jegou, 2007). Maturity for males was studied using a dataset on years 2004–2005 and size of functional maturity was set at 26 mm CL (Jegou, 2007).

Growth

Nephrops grow by successive moults like all crustaceans, when renewing their carapace. Individual growth by sex for the FU23–24 *Nephrops* is assumed to be modelled by a Von Bertalanffy function (see a wide panel of tested growth models investigated by Verdoit *et al.*, 1999). The currently used equations are expressed by:

Males and immature females : $L(t) = 76*(1-\exp(-.14*t))$

Mature females : $L(t) = 56*(1-\exp(-.11*t))$

(lengths are provided in carapace length in mm).

Natural mortality

No recent experiment on natural mortality estimation was carried out. The reference of Morizur (1982) was used throughout the time-series and instantaneous coefficients of 0.3 for males (and immature females) and of 0.2 for mature females were applied. Current explorations (WKNEP, 2016) seem to demonstrate that the actual natural mortality should be higher for both sexes although it was not yet decided to modify the historical values.

8.6.4 Commercial dataseries

Up to 1998, the majority of the vessels were not obliged to keep logbooks because of their size and fishing forms were established by inquiries. Since 1999, logbooks became compulsory for all vessels longer than 10 m. The available logbook data cannot be currently considered as representative for the fishing effort of the whole fishery during the overall time-series. Hence, since 2004, it was attempted to define a better effort index.

Effort data indices, landings and lpue for the “Le Guilvinec District” *Nephrops* trawlers in the 2nd quarter (noted GV-Q2) are available for the overall time-series 1987–2015 (Figure 9.6.4.5; Table 9.6.4.3).The lpues of the GV-Q2 fleet were reasonably stable for a long period, fluctuating around a long-term average of 13.3 kg/hour, with three pics values occurring in the past (1988, 2001 and 2010). Lpue increased steeply between 2009 and 2010, then strongly decreased in the period 2011–2013. The GV-Q2 lpue index remained stable in 2014, but it reached the historically highest level in 2015 (19.5 kg/h).

Changes in fishing gear efficiency and individual catch capacities of vessels, imply that the time spent at sea may not be a good indicator of effective effort and hence lpue trends are possibly biased. Since the early 1990s, the number of boats using twin trawls increased (10% in 1991, more than 90% in recent years, almost 100% in the northern part of the fishery) and also the number of vessels using rock-hopper gear on the rough sea bottom of the extreme NW part of the central mud bank of the Bay of Biscay. Moreover, an increase in on-board computer technology has occurred. The effects of these changes are difficult to quantify as twin trawling is not always recorded explicitly in the fisheries statistics and improvement due to computing technology is not continuous for the overall time-series.

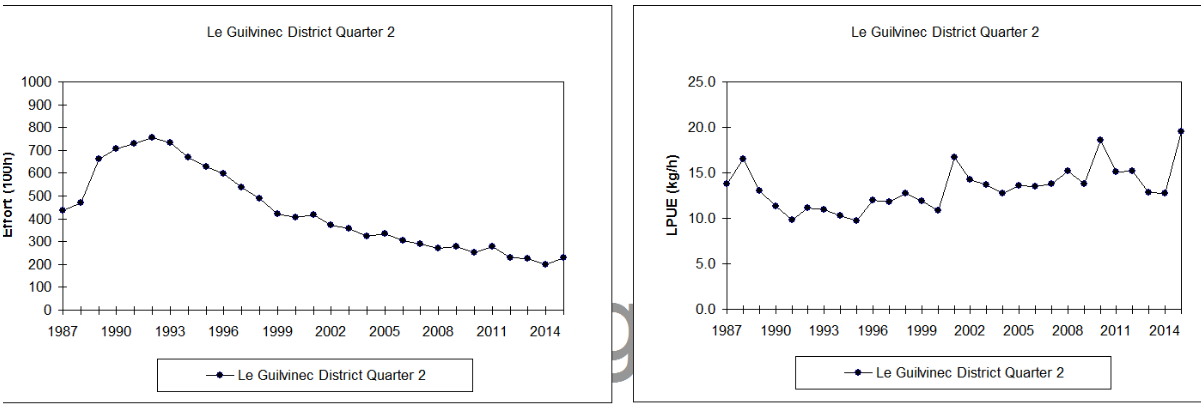

Figure 9.6.4.5. *Nephrops* in FUs 23–24 Bay of Biscay (8.ab). Effort and lpue values of standardised commercial fleets.

Table 9.6.4.3. ***Nephrops*** **in FUs 23–24 Bay of Biscay (8.ab). Effort and lpue values of commercial fleets.**

Sub-area VIII a,b

	Le Guilvinec District Quarter 2		
Year	Landings(t)	Effort(100h)	LPUE(Kg/h)
1987	603	437	13.81
1988	777	471	16.52
1989	862	664	12.99
1990	801	708	11.31
1991	717	728	9.84
1992	841	757	11.12
1993	805	735	10.96
1994	690	671	10.30
1995	609	627	9.72
1996	715	598	11.97
1997	638	539	11.83
1998	622	489	12.72
1999	505	423	11.93
2000	438	405	10.82
2001	697	417	16.71
2002	527	371	14.20
2003	487	356	13.68
2004	410	321	12.74
2005	455	336	13.57
2006	414	306	13.50
2007	401	291	13.76
2008	410	271	15.15
2009	384	279	13.78
2010	471	253	18.61
2011	422	279	15.13
2012	348	229	15.17
2013	288	224	12.83
2014	252	198	12.73
2015	451	231	19.52

8.6.5 Stakeholder data

Some information as VMS data on years 2012–2015 studied by WKNEP 2016 as well as lpue data for the standardised fleet GV-Q2 (see Section 9.6.4) are provided by the French Fisheries Direction although the whole compilation on this dataset is carried out by Ifremer.

8.6.6 Environmental data

Data involving in the sediment structure have been integrated in analysis and assessment for the Bay of Biscay *Nephrops* since the LANGOLF trawl survey 2006–2013. The heterogeneity of the area is still taken into account for estimating *Nephrops* abundance from the routinely conducted UWTV surveys since 2014. Additional data provided by the former trawl survey on the associated benthic community were investigated by a European project called BENTHIS (2013–2016). Moreover, the project TETRIS ("Testing the Effects of Trawl using Recorded Images at Sea") on interactions fishing activity/ecosystem has used the dataset from the UWTV tracks.

8.6.7 Other indicators-length distributions, etc.

Apart from LFDs on landings and discards by sex (Section 9.6.7.1) available on a long time-series, other LFDs obtained by the former LANGOLF trawl survey (2nd quarter 2006–2013) were exploited in the past. The dataset was included in the XSA assessment carried out in 2012–2014 (the first XSA output was rejected by the review group subsequently to the WGHMM 2012; the second one was rejected during the WGBIE 2014). This information as global indicator for the stock status was used for the advice 2014 (Figure 9.6.7.6).

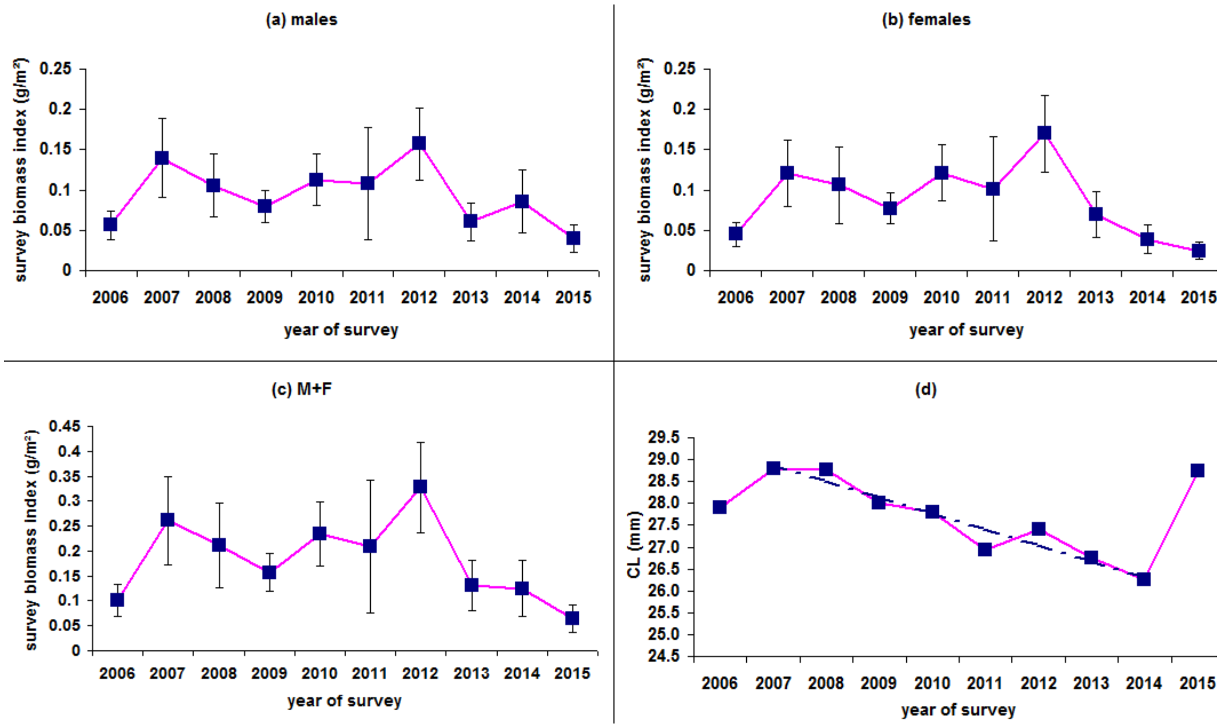

Figure 9.6.7.1. Biomass trawl survey LANGOLF indices (a) males; (b) females; (c) sex combined; (d) mean sizes (CL, mm) sex combined. Note: 2014 and 2015 data by experimental trawling associated to the UWTV survey are also included in the graphs.

8.7 Stock assessment model

As the WKNEP 2016 retained the UWTV survey for the stock, Separable Cohort Analysis (SCA) is the statistical model for estimating recruitment, selectivity and fishing mortality by fitting to catch (and discards) by length and sex. It is also possible to use an index of total abundance (combined sex) as an additional observation. This is not, strictly, an assessment model as it operates on length frequencies under the assumption of equilibrium (just as LCA does) and residuals from the model should be examined for evidence of gross departure from this assumption before any results are presented.

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

- Growth is continuous;
- Population is in equilibrium;
- Landings are taken throughout year.

The change in availability with respect to length only affects females and is a function of size at first maturity.

8.8 Short-term projections

8.8.1 Input data

Tables 9.8.4 and 9.8.5 below provide the main results of UWTV survey (correction factors, abundance indices) input in the SCA model. Calculations are carried out on the 2014 UWTV data[7] and on the averaged 2013–2015 LFDs on landings and discards (Table 9.8.6) (under two survival rate values for discards, 30% and 55%). Comparative values for correcting factors are given for the FU22 Smalls ground which was used as standardised stock reference.

Table 9.8.4. Correction factors for the number of burrows on the basis of the UWTV survey. Comparative examples between Bay of Biscay and Smalls Ground (FU22).

FU	Stock	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
23–24	Gascogne	1.145	0.94	1.05	1	1.13
				1.10		1.18
				1.15		1.24
22	Smalls	1.35	0.9	1.05	1	1.28

Table 9.8.5. Input parameters for the SCA model.

Landed numbers (10^3)	121 594	
Mean weight on landings (g)	23.08	
Survival rate (SR)	0.30[8]	0.55[9]
Dead discarded numbers(10^3)	82 551	53 069
Mean weight on discards (g)	11.25	
Numbers of removals (10^3)	204 145	174 663
Mean weight on removals (g)	18.30	19.49
Number of burrows (stratified statistics, 10^6)	5165	
Number of burrows (geostatistics, arithmetic mean, 10^6)	4856	
Number of burrows (krigging, 10^6)	4968	

The scenario for number of burrows currently involves in 4856 million (arithmetic mean from geostatistics) combined with a cumulative bias correction factor of 1.18 i.e. equal to 4115 million of individuals.

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[7] 2014 was chosen because the area sampled in 2015 does not represent the whole Central Mud Bank whereas 2016 nominal statistics and LFDs on landings and discards are not yet available.

[8] See Charuau *et al*. (1982).

[9] See Méhault *et al*. (2015).

8.8.2 Model and software, how Y/R and SSB are derived

At the first *Nephrops* benchmark (ICES, 2009), two length based cohort models (LCA) were presented and adopted as methods for estimating harvest ratios that could be considered appropriate proxies for fishing at F_{MSY}. The SCA R-script routinely used for the UWTV surveyed stocks is a LCA completed version by including constraints vs. the number of burrows after correction accordingly to cumulative bias.

Growth: It is possible to rewrite the von Bertanalaffy growth equations to give the length of time spent in any given length interval. Assuming all recruits enter the system at the same size, it is then straightforward to project the decay of that cohort through time using the standard Baranov catch equations to give both population and catch numbers-at-length.

Table 9.8.6. LFDs for landings and discards (numbers in 10^3) by sex input in the SCA model. Averaged values on years 2013–2015.

CL (mm)	Males land	Males disc	Females land	Females disc
10.5				
11.5				
12.5		10		15
13.5		59		12
14.5		19		23
15.5		39		485
16.5		544		1112
17.5		1319		175
18.5		1767		1984
19.5		3128	2	3752
20.5	0	493	16	4369
21.5	18	5858	2	5952
22.5	170	773	39	7336
23.5	358	8851	65	9658
24.5	895	879	1612	8743
25.5	2493	8489	2764	9718
26.5	4454	6569	4814	62
27.5	6478	4211	622	4297
28.5	7446	2669	6381	2633
29.5	7571	1744	6323	1667
30.5	7676	1251	4540	1192
31.5	7846	883	335	523
32.5	6986	90	2844	413
33.5	5233	343	284	178
34.5	4835	565	1385	114
35.5	3528	132	194	36
36.5	2856	229	64	69
37.5	240	135	498	22
38.5	1699	13	331	12
39.5	1599	85	236	24

CL (MM)	MALES LAND	MALES DISC	FEMALES LAND	FEMALES DISC
40.5	199	86	247	13
41.5	776	17	137	1
42.5	589	169	94	
43.5	468	115	47	2
44.5	323	4	5	
45.5	26	19	33	
46.5	170	15	22	
47.5	129	2	23	
48.5	10	8	3	4
49.5	100	8	16	
50.5	61		2	
51.5	48		7	
52.5	29		5	
53.5	30		3	
54.5	19		3	
55.5	14		3	
56.5	9		1	
57.5	16		1	
58.5	5		0	
59.5	7		0	
60.5	2		0	
61.5	1		3	
62.5	3		0	
63.5	1		0	
64.5	0			
65.5	1		0	
66.5	1		0	
67.5	0			
68.5	0			
69.5				
70.5	1			
71.5				
72.5				
73.5				
74.5	0		0	

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

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

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

UWTV outputs: In order to compare the modelled population to the estimates of abundance observed in the UWTV surveys a total population index was constructed. The modelled length frequency represents the continuous evolution of the population through time whereas the UWTV survey is a snapshot of population size at a particular point within the year subject to a survey selectivity function.

Figures 9.8.2.7–10 and Table 9.8.2.7 present output from the SCA model under the two survival rates and under two weighting factors in the script either by fitting against only LFDs (LCA output) or against UWTV results.

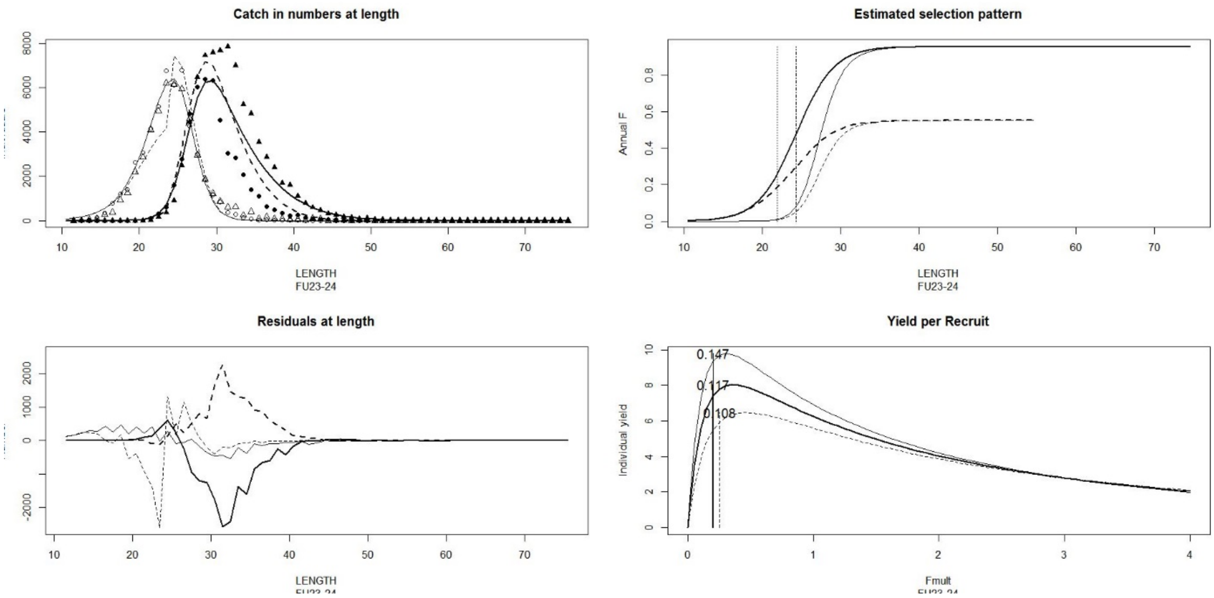

Figure 9.8.2.7. SCA results on the FU23–24 *Nephrops*. SR=0.30. Low weight for UWTV, high weight for LFDs of landings and discards.

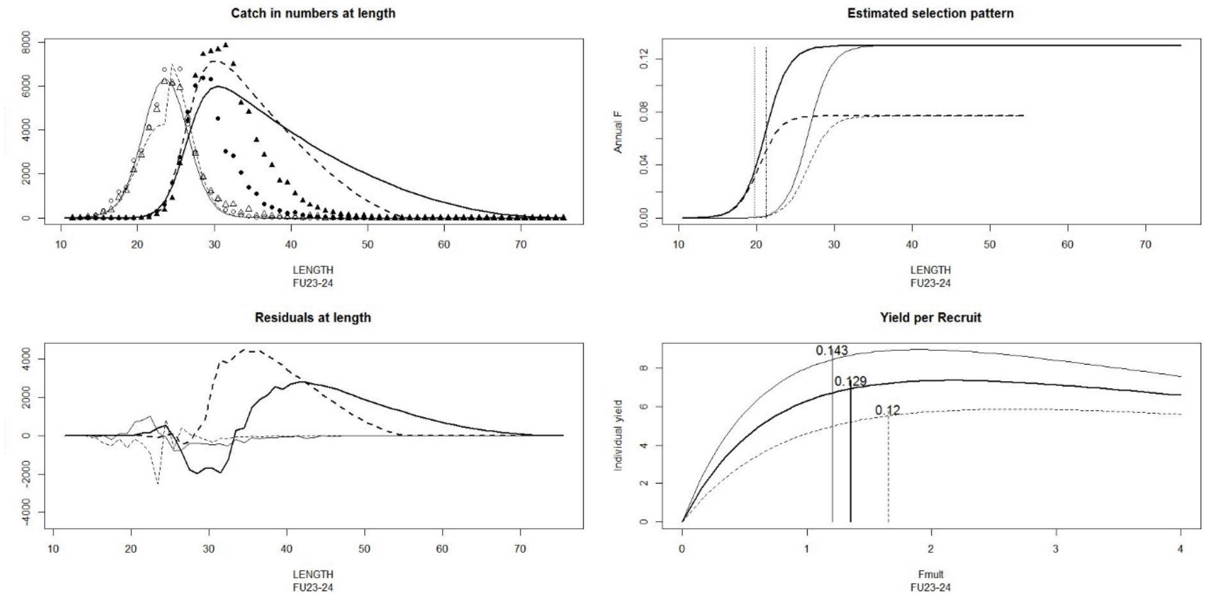

Figure 9.8.2.8. SCA results on the FU23–24 *Nephrops*. SR=0.30. High weight for UWTV, low weight for LFDs of landings and discards.

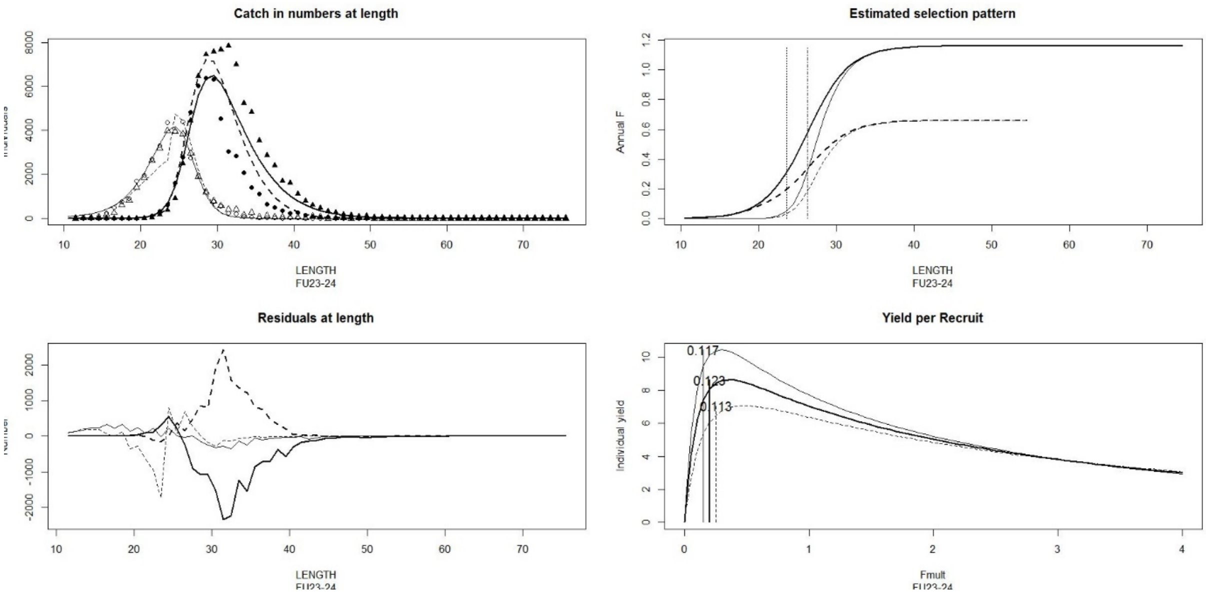

Figure 9.8.2.9. SCA results on the FU23–24 *Nephrops*. SR=0.55. Low weight for UWTV, high weight for LFDs of landings and discards.

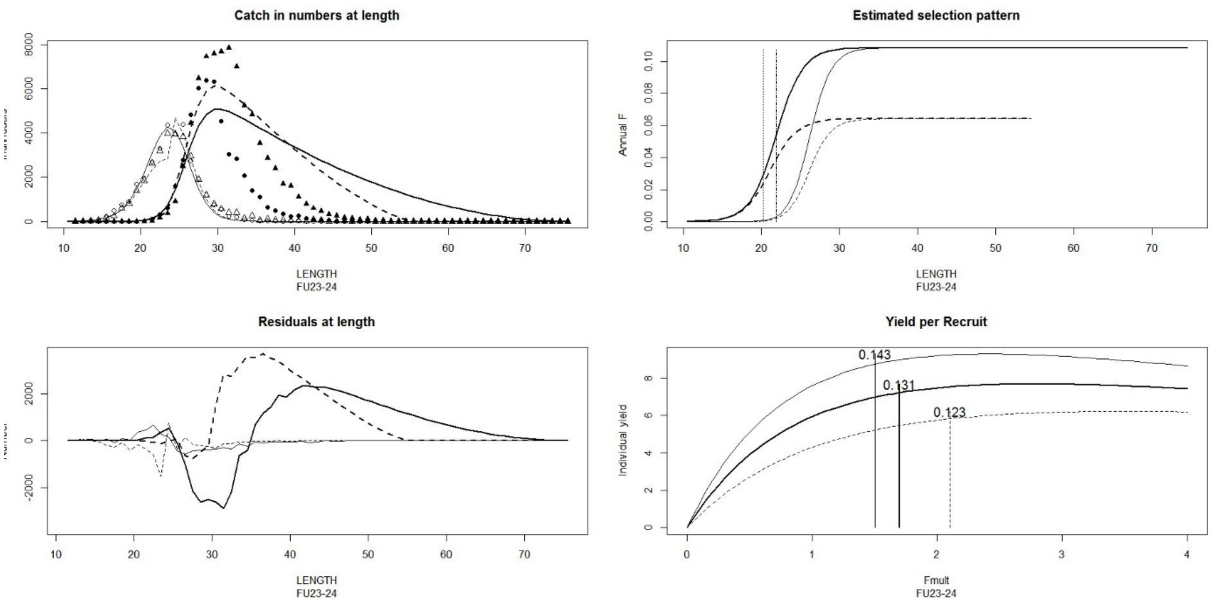

Figure 9.8.2.10. SCA results on the FU23–24 *Nephrops*. SR=0.55. High weight for UWTV, low weight for LFDs of landings and discards.

Table 9.8.2.7. FU23–24 *Nephrops*. Output from SCA model. Proxys ($F_{0.1}$, $F_{35\%SPR}$, F_{MAX}) for values of fishing mortality and for harvest rates (percentages). Comparison with the *status quo* level (Fsq).

		SR=.30 (remov=204.145)				SR=.55 (remov=174.663)			
		males	females	combined		males	females	combined	
	population			640.245				569.192	
LFDs	F0.1	0.147	0.108	0.117	9.1%	0.117	0.113	0.123	9.5%
	F35%	0.184	0.173		12.9%	0.196	0.181		13.1%
	Fmax	0.220	0.195	0.204	14.6%	0.235	0.226	0.216	14.8%
	Fsq	0.734	0.433	0.584	31.6%	0.782	0.452	0.617	29.9%
	population			4097.657				4102.061	
UWTV	F0.1	0.143	0.120	0.129	10.1%	0.143	0.123	0.131	10.1%
	F35%	0.184	0.164		13.4%	0.182	0.163		13.0%
	Fmax	0.226	0.193	0.206	15.3%	0.229	0.204	0.216	15.7%
	Fsq	0.119	0.073	0.096	7.6%	0.096	0.058	0.077	6.2%

8.9 Reference points

8.9.1 Reasoning behind the reference point values

The runs of the cohort based models resulted in radically different population estimates compared to the TV abundance (differences of ~5–6 fold), coupled to high estimates of fishing mortality. On the basis of the LCA output, the stock is heavily overexploited. Under the assumption of a survival rate of 30%, F_{sq}=0.584 compared to $F_{0.1}$ of 0.117. However, when the SCA model is forced to fit to the UWTV survey, Fsq drops to 0.096 and $F_{0.1}$ moves to 0.129 but the fit to the length distribution is very poor.

Other runs were also curried out during the workshop and it seems that much higher values of natural mortality by sex (M=0.85 for males and 0.70 for mature females) give a good convergence between the two options (weighting on LFDs or on UWTV). However, those M values are unlikely as regards to the demographic pattern for the species even if some simulations undertaken during the WKNEP 2016 suggest that the actual natural mortality should be stronger than the current one. Additionally, explorations on L∞ and K parameters by sex show that there could be over-estimation of L∞ for males and under-estimation for females, thus because of the uncertainty on the overall set of biological parameters the historically accepted values for M remained unchanged.

Reconstructing the total mortality from the length distribution of catches by a Jones cohort analysis indicated fishing mortality-at-length being very different from the assumed logistic function; however, this deviation from model assumption is unlikely to be the sole cause of the difference between population abundance estimates. Although the estimates of population size and fishing mortality from the LCA are not used as measures of stock status, the group felt that these discrepancies were so great that there was a significant risk of the LCA derived estimates of fishery parameters and their associated MSY proxy points being biased.

The workshop retained the option of calculation under high weight on the UWTV results (the survival rate seems to have a minor contribution, 30% is currently applied), then the reference points for the stock are defined vs $F_{0.1}$.

8.9.2 Recommended exploitation level

The group therefore considered it appropriate to convene a study group to propose methods for deriving advice from direct absolute measurements of stock abundance, in general and for *Nephrops* measured by UWTV surveys in particular.

The *status quo* harvest rate is between 5.5–7.5% depending upon which survival rate for discards is assumed. The $F_{0.1}$ proxy corresponds to a harvest rate of 10% and the workshop recommended to move gradually towards this level however it acknowledged that there is no with no current definition of the transition scheme. That implies that the stock is not overexploited even if the typical LCA outputs suggest growth overfishing.

It is noticeable that for other routinely UWTV surveyed stocks of the same density level the currently estimated harvest rate fluctuates around 10%. As the UWTV method was recently initiated for the FU23–24 stock this should be examined cautiously for the definition of the transition scheme towards $F_{0.1}$.

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9 *Nephrops* in FU 30

9.1 Multispecies and mixed fisheries issues

9.1.1 Trophic interactions

9.1.2 Fishery interactions

A unique and highly multispecific métier (OTB_MCD≥55_0_0) has been identified in the Gulf of Cadiz since 2007 (Castro *et al*., 2007; Castro *et al*., 2011). This métier is defined as bottom otter trawl targeting a variety of crustaceans, cephalopods and demersal fish using a mesh size of 55 mm (rose shrimp, *Nephrops*, tiger shrimp, spottail shrimp, Octopus, squids, cuttlefish, hake, mullets, sparids, wedge sole, sole, horse-mackerel within others).

There are two main target crustacean species in this fishery, which are the Norway lobster and the deep-water rose shrimp (*Parapenaeus longirostris*). These two species have a different but overlapping depth distribution (Ramos *et al*., 1996). Rose shrimp occurs from 90 to 380 meters of depth whereas Norway lobster is distributed from 200 to 700 meters. The number of fishing trips directed to one species or to the other depends on the abundance of rose shrimp each year because rose shrimp achieves a higher market value and its fishing grounds, less deep and closer to the coast, are easier to reach. *Nephrops* grounds are allocated far away from ports and the fleet decides when they want to go fishing *Nephrops*.

9.2 Impacts of the fishery on the ecosystem

9.3 Ecosystem drivers

9.4 Stock identity, distribution and migration issues

The *Nephrops* stock from FU30 comprises the Spanish waters of the Gulf of Cadiz. The western limit of the stock is at the Portuguese border, on the Guadiana River estuary, whereas the eastern border is at the Gibraltar Strait. The Gibraltar Strait separates the Gulf of Cadiz from the Mediterranean Sea and is considered a natural border. On the other hand, the Guadiana River does not seem to be a real boundary for splitting possibly different populations (FU 29, South Portugal and FU 30, Gulf of Cadiz). This stock limit was decided mainly on management considerations, without any clear biological basis. Possible differences and exchange rates across FUs 29 and 30 should be studied. Tagging experiments, genetic and dynamic larvae studies could provide valuable information in this respect.

Within FU 30, the *Nephrops* stock is distributed in muddy and sandy areas ranging between 200 to 700 m depth. Different sources of information have been used to know the *Nephrops* distribution area (see WD in WKNEP 2016, Vila *et al*., 2016). The analysis of the VMS data of fishing activity together to logbooks in the years 2012 and 2013 was mainly used to delineate the limits of the *Nephrops* ground. Additionally, the *Nephrops* abundance from International Bottom Trawl Surveys (1993–2015 time-series) carried out yearly in spring and autumn in the Gulf of Cadiz, bathymetric information obtained from the LIFE-INDEMARES/CHICA project (www.indemares.es), and sedimentary analysis from the first ISUNEPCA UWTV survey carried out in 2014 (Vila *et al*., 2015) have helped to know the *Nephrops* distribution area in the Gulf of Cadiz.

The *Nephrops* distribution observed from the bottom trawl surveys is in concordance with the spatial distribution of the fishing activity on the ground in the Gulf of Cadiz (200–650 m depth) (Figure 10.4.1). Nevertheless, small quantities of *Nephrops* occur below 200 m isobaths and on the deepest area (about 600–700 m) although none bottom trawl fleet activity targeting to *Nephrops* is observed in the VMS. The particular bathymetry on this area shows deep channels with strong currents in the border deepest that prevent the fishing activity and the *Nephrops* distribution (Figure 10.4.2). However, beyond this channel the composition of the substratum could be suitable for *Nephrops* constructs their burrows although maybe for the fleet it is a far away zone and it might not be profitable regarding to benefits since the *Nephrops* abundance seem low, according to trawl surveys information.

In the Gulf of Cadiz there are some mud volcanoes which could have a negative influence about *Nephrops* distribution and the fishing activity (Figure 10.4.2). The spatial distribution of the size grain in the sediment obtained in the 2014 ISUNEPCA UWTV survey shows sediments more classified near of these volcanoes (Figure 10.4.3). For example, near to Gazul volcano can be observed hard substratum with sponges and corals. Other zones where *Nephrops* fishing activity is absent correspond to bottom with a high percentage of sand (Figure 10.4.3). These types of sea bed are not appropriated for *Nephrops* since this species needs bottoms of muddy nature to be able to construct their burrows.

The *Nephrops* distribution area in the FU 30 has been estimated in 3000 km^2, which was used in the *Nephrops* abundance estimation from UWTV surveys in 2015 and 2016.

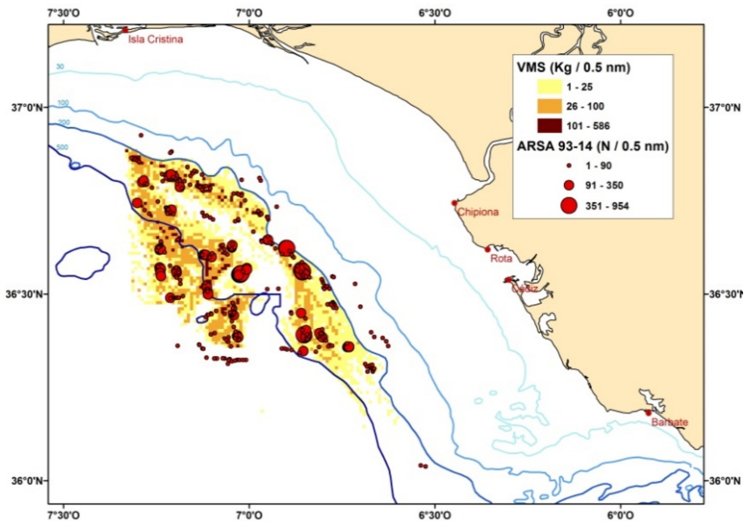

Figure 10.4.1. Results of the VMS analysis (2012–2013) and the *Nephrops* abundance obtained from the bottom trawl surveys (IBTS) series (1993–2014) carried in the Gulf of Cadiz.

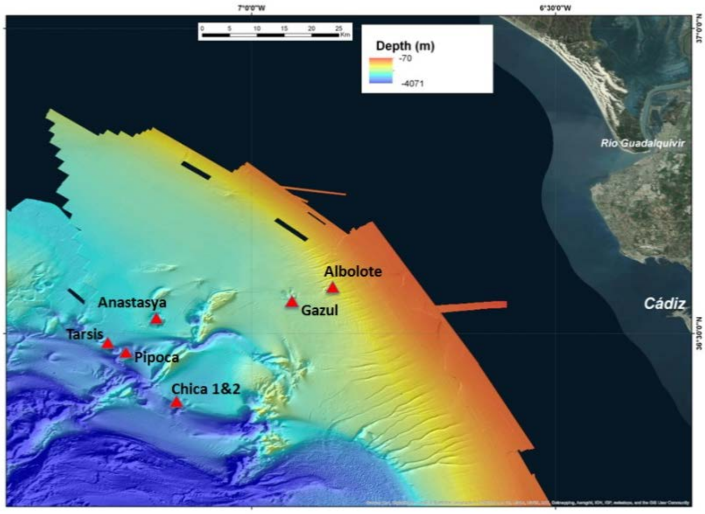

Figure 10.4.2. Bathymetry of the Gulf of Cadiz. Mud volcanoes allocated in the Gulf of Cadiz is also shown. (Source: bathymetry from INDEMARES_Chica project).

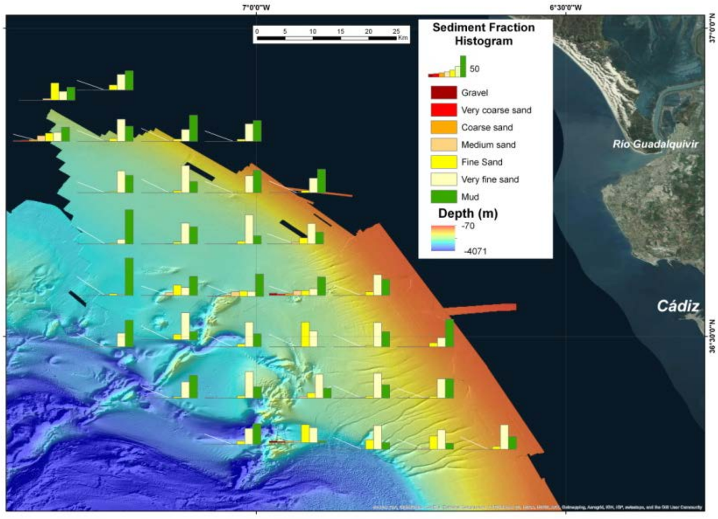

Figure 10.4.3. Spatial distribution of the grain size obtained from samples taken during the IS-UNEPCA UWTV survey in 2014. (Source: bathymetry from INDEMARES_Chica project).

9.5 Influence of the fishery on the stock dynamic

9.6 Influence of environmental drivers on the stock dynamic

9.7 Stock assessment data and information

9.7.1 Catch and landings data-quality, misreporting, discards, selection at-length

Landings are reported by Spain and also minor quantities by Portugal (Table 10.7.1.1). Spanish landings are based on sale notes which are compiled and standardized by IEO.

Since 2013, trips form sales notes are also combined with their respective logbooks, which allow georeferencing the catches.

Nephrops total landings in FU 30 shows an increasing trend from 49 t in 1996 to 307 t in 2003, the highest value recorded in the time-series. In 2004, landings decreased more than 50% but it increased again until a mean value of 235 t in 2005–2007 period. After this period, landings declined to 120 t in 2008 and remained relatively stable around 112 t between 2009 and 2012. During the last three years, total landings dropped dramatically to about 25 t (Figure 10.7.1.1). This drop was caused because the quota was exceeded in 2012 and the European Commission applied a sanction to be paid in 2013–2015 period. So, the fishery was closed almost all year in 2013 and a TAC reduction in these three years was applied.

A modification of Fishing Plan for the Gulf of Cadiz (AAA/1710/2014) was established in 2014. This new regulation establishes an assignation of the *Nephrops* quotas by vessel. This fact joined to the low TAC assigned to FU 30 and the reduction even more of the quota during the penalty period might cause unreported landings between 2013 and 2015.

An annual Spanish Discard Sampling Program under the EU DCR has been carried out in FU 30 since 2005. Until 2008, fishing trips in the bottom trawl métier were sampled by observers on board during the *Nephrops* fishing season (summer). The discard sampling scheme covers the whole year since 2009 (Reg. EC 1343/2007). The discard is considered negligible in this FU (<2% in weight) and only a few damaged individuals are discarded. So, information on discards is not taken into account in the estimation of the total catch length distribution due to the low level of discards.

Table 10.7.1.1. Landings in FU 30 by country.

Year	Spain**	Portugal	Total
1994	108		108
1995	131		131
1996	49		49
1997	97		97
1998	85		85
1999	120		120
2000	129		129
2001	178		178
2002	262		262
2003	303	4	307
2004	143	4	147
2005	243	3	246
2006	242	4	246
2007	211	4	215
2008	117	3	120
2009	117	2	119
2010	106	1	107
2011	93	3	96
2012	115	1	116
2013	26	<1	27
2014	14	<1	15
2015	25	<1	25

** Ayamonte landings are included since 2002

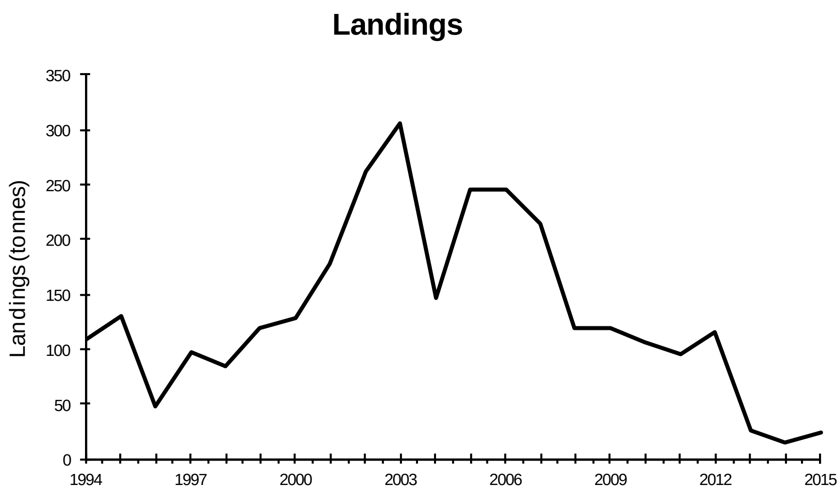

Figure 10.7.1.1. Long-term trend in landings.

9.7.2 Survey data

IBTS

Two ground fish surveys (IBTS) are carried out yearly in the Gulf of Cadiz in March (since 1994) and November (since 1997). The area covers 7224 km^2 and extends from 15 to 800 m depths. This survey follows a stratified random sampling design with five bathymetric strata (15–50 m, 51–100 m, 101–200 m, 201–500 m and 501–700 m) (Figure 10.7.2.1). *Nephrops* is caught in the two deepest strata. The number of hauls in each depth stratum is proportional to trawlable surface and the haul duration is 60 minutes.

All hauls are carried out during daylight hours using Baka 40/60 trawl fear with a 43.6 m footrope and 60.1 m headline. An inner 20 mm mesh codend liner is used to prevent the escape of small individuals.

Neither of these surveys is carried out during the main fishing period of *Nephrops* (April–September). Berried females are hidden in their burrows in autumn, so only the index from the March survey is considered potentially representative of the stock abundance. The trawl index shows an increasing trend since 2013 (Figure 10.7.2.2).

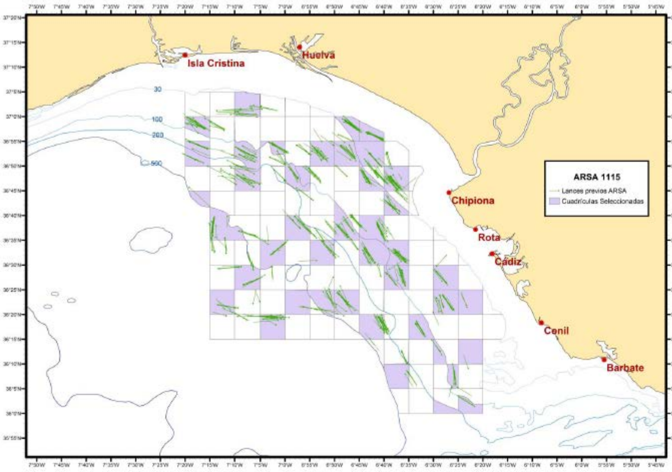

Figure 10.7.1.1. Random stratified sampling design in the bottom trawl survey carried out in the Gulf of Cadiz (this map corresponds to November 2015). Blue squares are the selected squares for this survey and green lines correspond to the hauls carried out in these squares in the historical time-series.

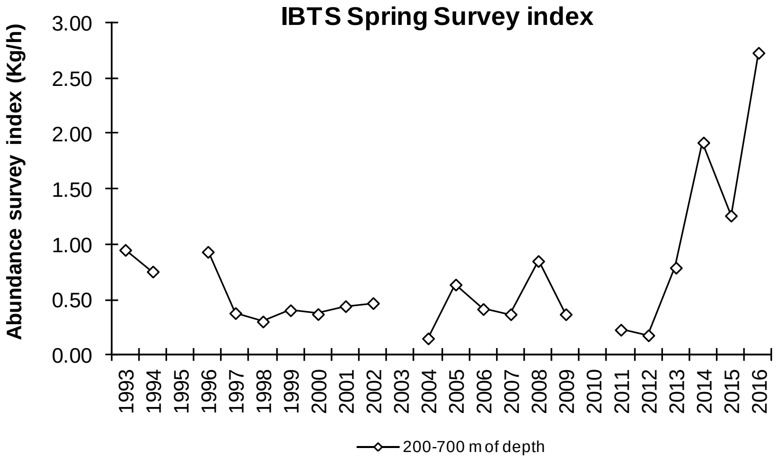

Figure 10.7.2.2. Abundance index from bottom trawl spring survey (IBTS).

UWTV

An exploratory *Nephrops* UWTV survey on the Gulf of Cadiz fishing ground was carried out in 2014 within the framework of a project supported by Biodiversity Foundation (Spanish Ministry of Agriculture, Food and Environmental) and European

Fisheries Fund (EFF) (Vila *et al*., 2014). Since 2015, IEO carries out yearly ISUNEPCA-UWTV survey in June.

ISUNEPCA-UWTV surveys follow a randomized isometric grid design with stations spaces 4 nm since 2015. The number of stations valid and used into the *Nephrops* density estimation was 58 in 2015 and 2016. Additionally, a number of stations on the shallower *Nephrops* distribution area were planned in order to confirm the *Nephrops* limits. Unfortunately, few stations could be completed into the each survey time window and all of them realized were considered null because the water visibility was very poor. The area used to raise the burrow density and estimate the *Nephrops* population abundance is 3000 km^2 (Figure 10.7.2.3).

The method used during the survey are according to WKNEPHTV (ICES, 2007), WKNEPHBID (ICES, 2008), SGNEPS (ICES, 2009, 2010, 2011) and WGNEPS (2013, 2014, 2015). A description of the UWTV surveys carried out in FU 30 since 2014 is documented in a WD 8 presented in WKNEP 2016 (Vila *et al*., 2016).

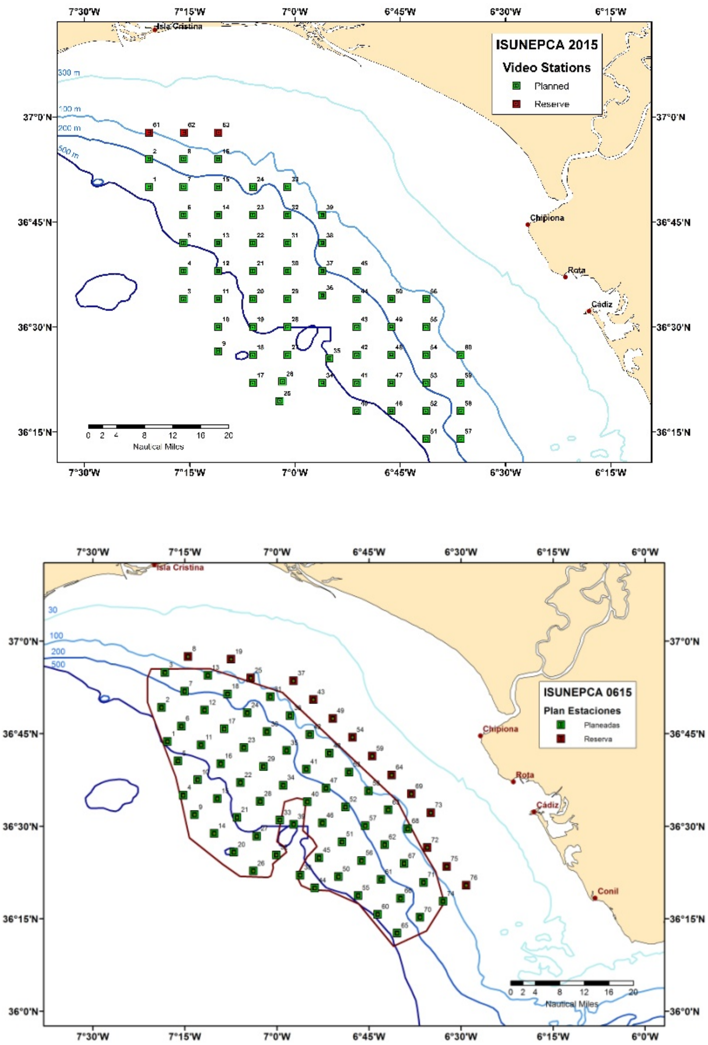

Figure 10.7.2.3. Stations grid planned in ISUNEPCA UWTV survey in 2015 (above) and 2016 (below). Stations in red symbols correspond to stations planned in order to confirm the *Nephrops* distribution area (red line).

The mean burrow density observed in 2015, adjusted for the cumulative bias, was 0.097 burrows/m² while a lower mean burrow density was observed in 2016 (0.075 burrows/m²). In general, the range of the observations was relatively high in both years (0.00–0.345 burrows/m² in 2015 and 0.00–0.328 burrows/m²).

The final modelled density surfaces in 2015 and 2016 are shown as a heat maps and bubble plots in Figure 10.7.2.4. The abundance estimate derived from the krigged burrow surface (and adjusted for the cumulative bias) was 298 million burrows (CV= 7.6%) in 2015 and 232 million burrow (CV=7.3%) in 2016.

In ISUNEPCA UWTV survey carried out in 2015, the number of stations and the space between them was increased in relation to 2016. However, the border was under sampled mainly in the shallower limit. In addition, an overestimation of the number of burrows may have happened. Many participants in the survey were not experienced in the quantification of *Nephrops* burrows. These facts can influence in the geostatistic analysis. In 2016, the stations covered better the area, with more stations in the border. Moreover, the identification of the *Nephrops* burrows was carried out for three scientists who participated in the two previously surveys and therefore with more experience. A more realistic result was obtained in ISUNEPCA 2016 according to the VMS information.

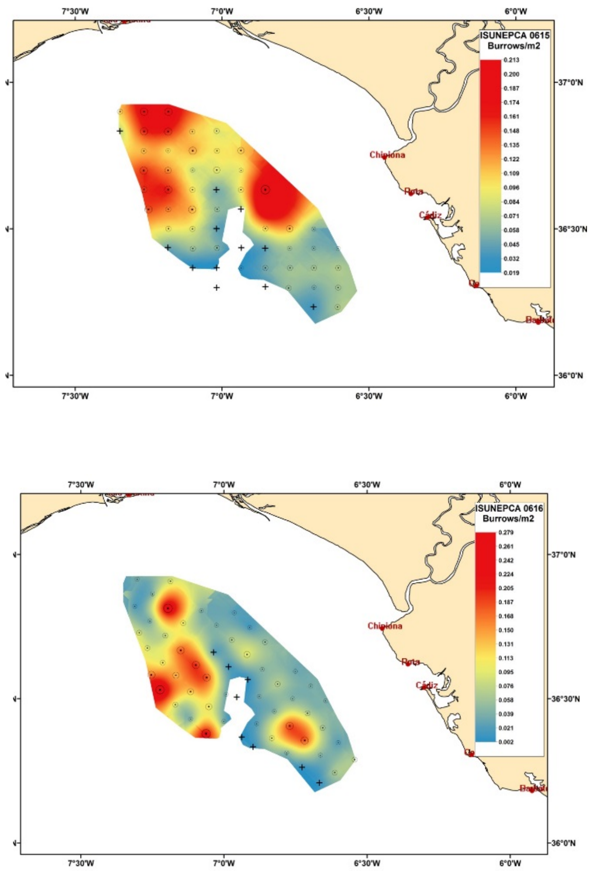

Figure 10.7.2.4. ISUNEPCA UWTV bubble plot of the burrow density observations overlaid on a head map of the krigged burrow density surface for 2015 (above) and 2016 (below). Station positions with zero density are indicated using a +.

UWTV Survey relative to absolute conversion factors

A number of factors are suspected to contribute bias to UWTV surveys (ICES, 2007). In order to use the survey abundance estimate as absolute it is necessary to correct for these potential biases. The main bias is the "edge effect" which is a moderate source of overestimation when deriving *Nephrops* population size from underwater TV surveys. This bias is related to the counting of burrow complexes which lie mainly outside the viewed track. The field of view of the camera is 0.75 cm and the expert judgment of the mean burrow diameter is 27 cm. The estimated edge effect bias using the simulation approach suggested by Campbell *et al*. (2009) is established in 1.24. Other bias identifies are the "burrow detection" and "burrow identification regarding to visibility quality and the presence of other burrowing macro benthic species, respectively. The burrow detection rates were thought to be relatively high due to good water clarity. Burrow identification could be overestimated since some squat lobsters were observed at burrow entrances. Regarding to the "occupancy", is assumed that 100% of burrows are occupied for an individual of *Nephrops*. The proposed cumulative correction factor for the Gulf of Cadiz was 1.28.

	Edge	Detection	Species	Occupancy	Cumulative
FU30: Gulf of Cadiz	1.24	0.90	1.15	1	1.28

9.7.3 Biological data–weights, maturities, growth, natural mortality

No analytical assessment has been carried out for *Nephrops* in FU30 up to date and few or old information was available for this stock. The last length–weight relationship by sex was estimated in 2005 (Vila *et al*., 2005) and a sex combined length–weight relationship has been estimated recently (Torres *et al*., in press). Reproductive information has been analysed only for female with data from 2004 (Vila *et al*., 2005; Vila *et al*., 2006), including the spawning season and the size at first maturity.

Regarding to the von Bertalanffy growth parameters no specific information exists for this stock. Length–frequency distributions in FU 30 do not show clear modes and they are complicate to use. The identification of age groups and their mean lengths-at-age as well as the estimation of the growth parameters in *Nephrops* proved to be difficult (Mytilineou *et al*., 1998). Castro *et al*. (1998) suggest that the modal progression analysis is not appropriate for this species because the modes do not progress in a manner that allows the following of a particular group. Tagging–recapture experience never has been proposed in FU 30 although it could be result problematic because *Nephrops* in the Gulf of Cadiz is distributed between 200–700 m of depth.

In this WKNEP 2016 a recollect of the available data has been carried out and different biological parameters have been estimated (size maturity, length–weight relationship and the growth parameters in males and females). A description of the methodology used and the results obtained is detailed in Annex 2 working document 7 presented in WKNEP 2016 (Vila, 2016). A summary of the biological parameters estimated are shown in Table 10.7.3.1. WKNEP 2016 did not had any decision regarding to which of two criteria used for estimate the size at first maturity in females must be adopted.

Table 10.7.3.1. Biological parameters in FU 30.

FU 30	Males	Females
Size at first maturity	30 mm	Criteria 1* 25.6 mm
		Criteria 2* 28.6 mm
Growth-K	0.167	0.135
Growth-L_∞	66 mm	61 mm
Length-Weight-a	0.000845	0.001873
Length-Weight-b	2.953452	2.726119

***Criteria 1: females in stage II–V&ovigerous.**

***Criteria 2: females in stage III–V&ovigerous.**

In general natural mortality estimates in *Nephrops* is weak. A natural mortality rate of 0.3 is assumed for all age classes and years for males and immature females and a value of 0.2 for mature females based in Morizur (1982). The lower value for mature females reflects the reduced burrow emergence while ovigerous and hence an assumed reduction in predation. In WKNEP 2016, natural mortality in FU 30 was estimated by the Hierarchical Mean Length and Effort Model for 2005–2015 period. Natural mortality was estimated in 0.46 for males and 0.36 for females, higher than Morizur's estimate. However, it was not yet decided to modify the historical values. Trophic and predation studies should help to clarify this issue.

9.7.4 Commercial dataseries

The estimate of *Nephrops* directed effort corresponds to daily fishing trips for which *Nephrops* represent at least 10% of the total landings in weight.

The directed fishing effort trend is clearly increasing from 1994 to 2005, where the highest value of the time-series was recorded (4336 fishing days). After that, the effort declined to 2008 remaining relatively stable during 2008–2012 period (1400 fishing days mean value). The closure of the *Nephrops* fishery in 2013 and the penalty applied for exceeding the quota in 2012 resulted in a decrease of the fishing effort between 2013 and 2015 (283 fishing days mean value) (Figure 10.7.4.1).

Lpue obtained from the directed effort shows a gradual decrease from 1994 to 1998 (Figure 10.7.4.2). After 1998, the trend slightly increases until 2003. In 2004, the lpue decreases to the lowest value recorded (44.3 kg/fishing day). Lpue then increased until 2008 around 60% but declined again until 2010 (45.5 kg/fishing day). Since 2010, lpue shows an increasing trend with a high rise in 2013. Lpue index fluctuated in 2014 and 2015.

Lpue in last three years must be taken with caution due the special situation after the penalty in 2012 (closure of *Nephrops* fishery the most part of the year in 2013 and the reduction in the TAC for 2013–2015 period). These facts might increase the uncertainty associated to the commercial lpue index since 2013.

Figure 10.7.4.1. ***Nephrops*** **directed effort trend.**

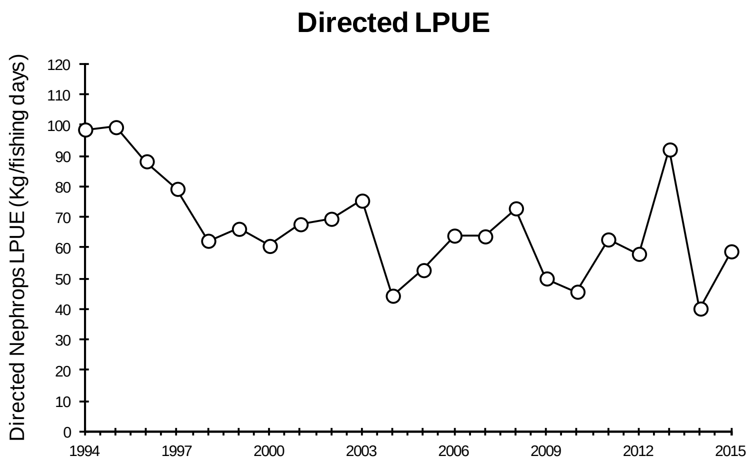

Figure 10.7.4.2. Directed ***Nephrops*** **lpue trend.**

9.7.5 Stakeholder data

9.7.6 Environmental data

9.7.7 Other indicators-length distributions, etc.

Commercial annual *Nephrops* length distribution series by sex in FU 30 are available since 2001. Length composition of landings is biased for the period 2001–2005 since the sampling of landings was not stratified by commercial categories (Silva *et al*., 2006). In 2006–2008, sampling was improved and covered all categories and a higher number of ports were sampled. Up to 2008, length–frequency distribution sampling was targeted to the species and it was carried out in port. The pan-European biological sampling program of commercial fish catch evolved from a stock-based (DCR 2002–2008) to a métier-based sampling scheme (DCF 2009–now). Since 2009 concurrent sampling is carried out, as required by the DCR. With this sampling strategy, fishing trips of the unique multispecific bottom otter trawl métier (OTB_MCD>=55_0_0) are sampled on board vessels (Annexe 2, working document 6 by Castro *et al*., 2016). Figure 10.7.7.1 shows *Nephrops* length distribution by sex in FU 30 since 2009.

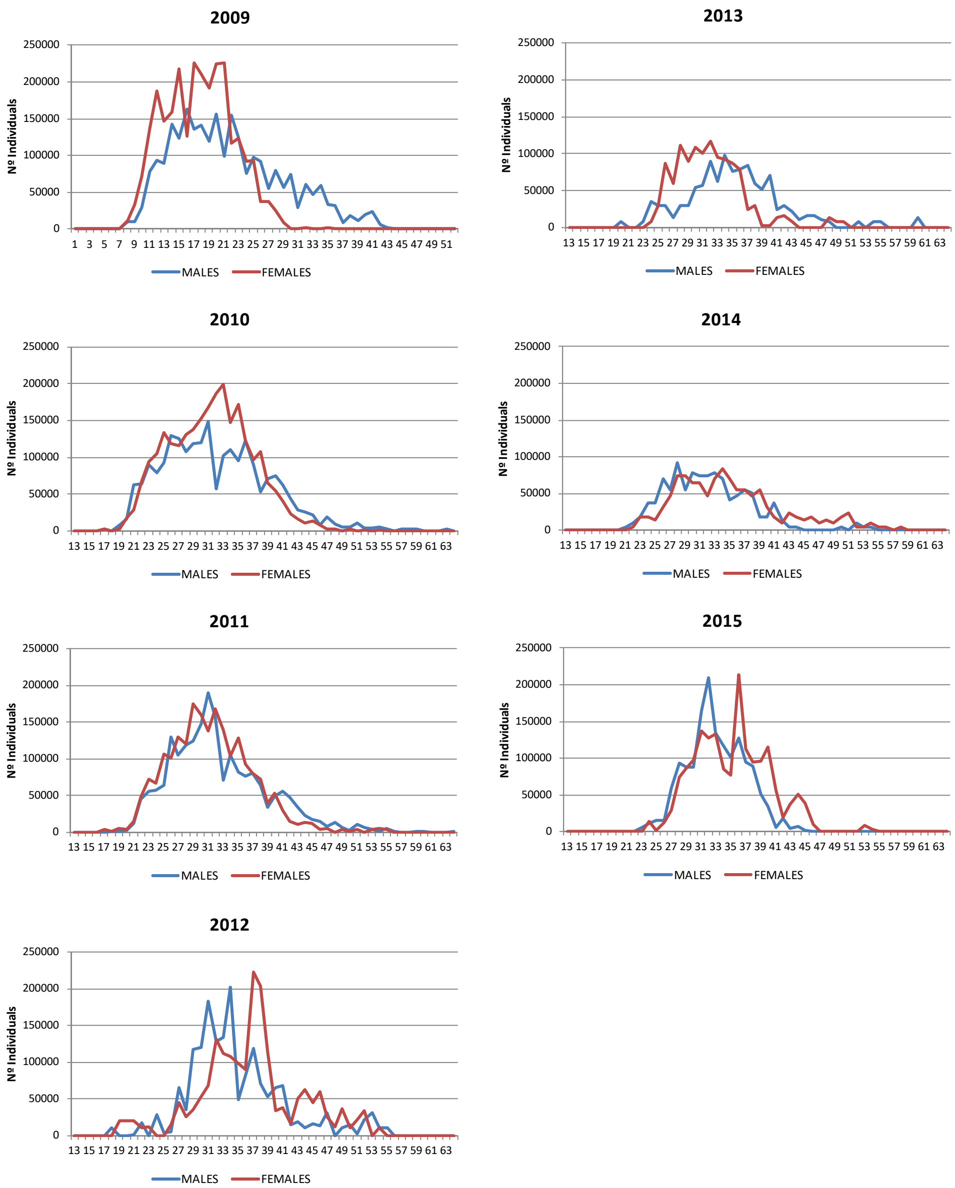

Figure 10.7.7.1. Commercial annual *Nephrops* length distribution by sex from 2009 to 2015 in FU 30.

However, a higher proportion of observed trips are likely to not cover *Nephrops* catches in the concurrent sampling (Figure 10.7.7.2), mainly in first and four quarter (outside of the *Nephrops* fishing season) whereas when *Nephrops* sampling were carried out in the harbour in the past, the length distribution of landings were covered in all months. In addition, high numbers of refusals are recorded. These facts together with the low number of individuals sampled by sex could be affecting to the length distribution obtained where the global sex-ratio remain stable about 50% in the time-series, when the percentage of males should be higher. The random sampling does not assure length distributions in all quarters.

In summer 2016, a number of trips directed to *Nephrops* were carried out in order to supervising the biometric sampling on board within others issues (Annexe 2 working document 6). Curiously enough, the sampling in the third quarter was cover only because a directed sampling was carried out (see Figure 11, year 2016). So, the random sampling should be enforcing with samplings directed to *Nephrops* in order to obtain length distributions that cover the whole of the year. On the other hand the number of individuals sampled must be increased.

Nephrops mean size for commercial landings and bottom trawl spring surveys (IBTS) are shown in Figure 10.7.7.3. A lightly increase is observed in mean size in landings since 2009. However, mean size in bottom trawl spring survey is maintained relatively stable.

Information on discards is not taken into account in the estimation of the total catch length distribution due to the low level of discards. The discard is considered negligible in this FU.

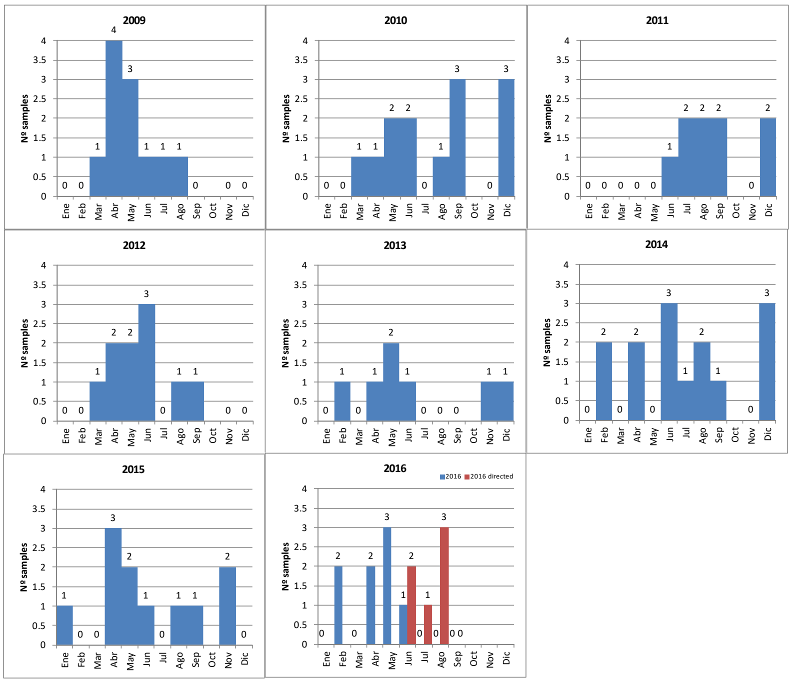

Figure 10.7.7.2. Sampling level of length–frequency distribution for 2009–2015 period. Sampling in 2016 until the third quarter is also shown. Red bars correspond to *Nephrops* directed sampling.

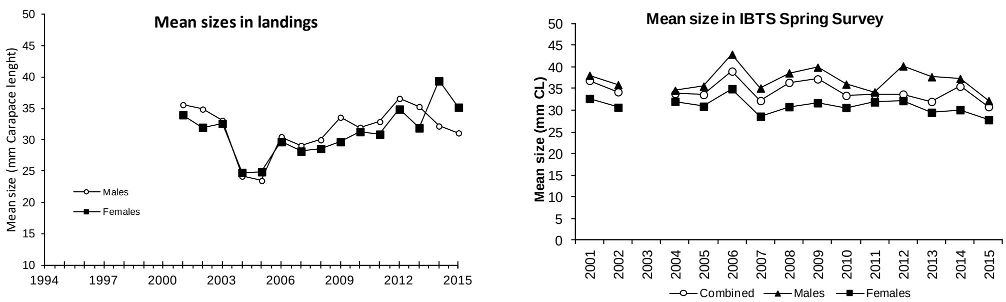

Figure 10.7.7.3. Mean size in landings (left) and in IBTS Spring survey (right).

9.8 Stock assessment model

Model used: UWTV based approach to generate catch options.

In 2009 WKNEPH agreed that the bias corrected UWTV survey abundance estimates (considered as an absolute abundance index) could be used directly in the formulation of catch advice (ICES, 2009). Separable Cohort Analysis can be used to estimate sustainable stock specific Harvest Ratio reference points.

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

Multiplying the HR by the assessed stock abundance in number obtained from the UWTV survey provides a recommended number of removals. This may be converted to landings by subtracting dead discard and then multiplying by the expected mean weight in landings in order to produce landings biomass (ICES, 2009; ICES, 2013b).

9.9 Short-term projections

9.9.1 Input data

A SCA (separable cohort analysis, model Bell) was used to estimate sustainable stock-specific Harvest Ratio reference points. Negligible discards are recorded by observers on sampled trips in FU 30 and therefore, no discards will be taken into account for the calculation of catch options.

An LCA should be fitted to recent observed removals length distributions. In general, a three year average length distribution is used but this also depends on the quality of the available data (ICES, 2013). For FU 30, the SCA model was fitted to a 3-year moving average window of length–frequency distributions (2013–2015, 2012–2014, 2011–2013, 2010–2012, 2009–2011). Finally, SCA based on length–frequency distribution 2012–2014 was considered. Settings and initial parameters used are shown below.

Discard survival: 0%

FemMature<-c(27.3,29.4) L_{25}/L_{50} for female maturity

MalMature<- c(27.3,29.4) L_{25}/L_{50} for male maturity

n.indvs<-c(233) UWTV survey index (2016)

surv.time<-(0.56)

TV.sel<-c(16.5,17) TV Selectivity

Alpha<-c(0.000003) Survey weighting (low

f.range<-c(0, 0.01, seq(0.05, 4, 0.05) F.range for stimating the Yield-per-Recruit

discard.weight<-c(1) discard weighting

The model also has five initial parameters to estimate:

1) Initial population size at the smallest length class equal sex distribution assumed;
2) Length at 25% selection;
3) Multiplier on L_{25} to give L_{50};

4) Fishing mortalities at full selection for males and immature females;

5) Fishing mortalities at full selection for mature females.

Initial.parameters<-c(1.6,26,1.07,0.4,0.3)

Additional parameters required such as von Bertalanffy growth parameters, natural mortality and length–weight relationship parameters by sex are required. These parameters are given in Table 10.9.1.1.

Table 10.9.1.1. Input parameters for FU 30 SCA.

Parameter	Males	Immature Females	Mature Females
L_∞	66	66	61
K	0.167	0.167	0.122
Natural Mortality	0.3	0.3	0.2
Length-weight-a	0.0004909	0.0007881	0.0007881
Length-weight-b	3.1018161	2.9657572	2.9657572

An estimate of mean weight in the landings is required to calculate catch options using the methodology developed by WKNEP (ICES, 2009). In FU 30, the mean weight from 2013–2015 was used (30.937 g).

9.9.2 Model and software, how Y/R and SSB are derived

In WKNEP 2009, two modelling approaches were used to estimated sustainable stock-specific Harvest Ratio reference points; SCA (separable cohort analysis, model Bell) and Age Structured simulation model (model Dobby) (ICES, 2009).

In FU30, the SCA R-script, model Bell (ICES, 2015), was used for estimating harvest ratios which could be considered appropriate F_{MSY} proxies.

The ICES decision framework for F_{MSY} proxies is given in section 6.3. Given that the observed harvest rates are low and stock size estimates are new, the framework points to the use of F0.1, combined sex as the most appropriate of the candidate reference points.

Table 10.9.2.1 and Figure 10.9.2.1 show the output from SCA model, sex combined.

Table 10.9.2.1. Output from SCA model in *Nephrops* FU 30 for sex combined. Proxies ($F_{0.1}$, $F_{35\%SPR}$, F_{MAX}) for values of fishing mortality and for harvest rates (%). Comparison with the *status quo* level (Fsp) derived from 2010–2012 average.

		Harvest Rate
F0.1	0.12	9.60%
F35SpR	0.14	10.90%
Fmax	0.27	
$Fsq_{(2010\text{-}2012)}$		1.5%
Fsq_{2003}		4.0%

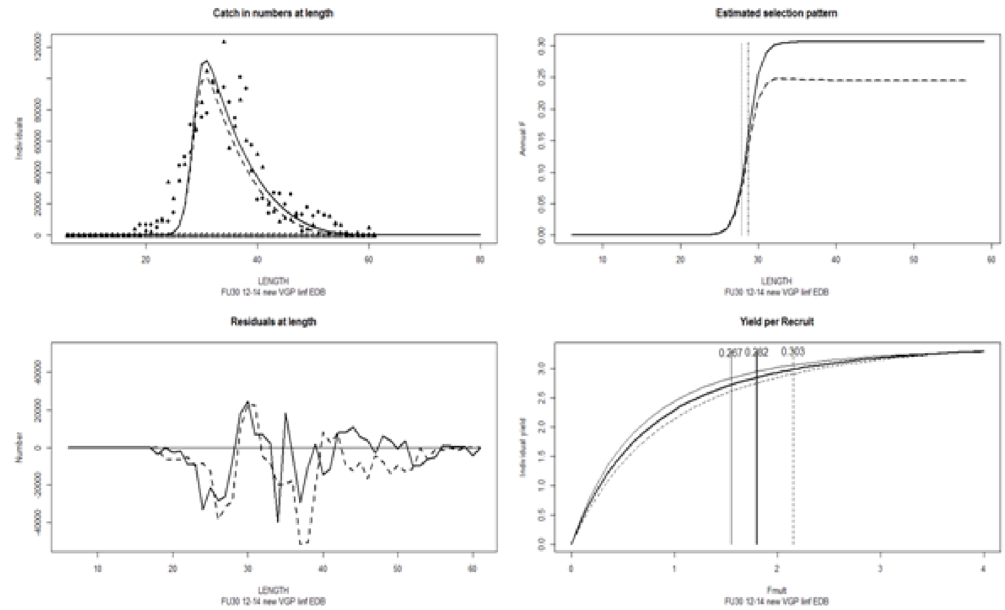

Figure 10.9.2.1. SCA results on the *Nephrops* FU 30 for the 2012–2014 average length distribution.

9.10 Reference points

9.10.1 Reasoning behind the reference point values

The runs of the cohort-based models resulted in poor fits and in radically different population estimates compared to the TV abundance (differences of ~tenfold), coupled to high estimates of fishing mortality even at times where the fisheries were very small. So, harvest rates derived from the SCA lead to much larger recommended catches than experienced historically.

Other runs were conducted using the natural mortality value obtained using the Hierarchical method during the WKNEP. These values (M=0.46 for males and M=0.36 for females) were much higher than the conventional values used in *Nephrops* stocks. The differences between the population estimates and the TV abundance were diminished but the recommended catch derived from the HR was even higher.

Reconstructing the total mortality from the length distribution of catches by a Jones cohort analysis indicated fishing mortality at-length being very different from the assumed logistic function. However, this deviation from model assumption is unlikely to be the sole cause of the difference between population abundance estimates. Although the estimates of population size and fishing mortality from the LCA are not used as measures of stock status, the group felt that these discrepancies were so great that there was a significant risk of the LCA derived estimates of fishery parameters and their associated MSY proxy points being biased.

9.10.2 Recommended exploitation level

Nephrops in FU 30 is a low density stock as shows the abundance estimate from UWTV survey and the lpue index. The $F_{0.1}$ proxy derived from the SCA model corresponds to a harvest rate of 9.6% but taken into account the fishery history, the HR ranging between 1.5% in recent years (2010–2012) and 4.0% when landings achieved the highest value (2003). The last period 2013–2015 is not considered because the situation of this fishery was abnormal due the very low TAC was limiting the fishery. In others routinely UWTV surveyed stocks of similar density level the currently estimated harvest rate fluctuates around 6%. So the WKNEP recommends setting an initial F_{MSY} proxy to 4% and moving gradually towards this level although it is acknowledged that the ICES MSY framework does not have a designated transition scheme. As the UWTV approach is recently initiated for the FU 30, this should be examined with caution for the definition of the transition scheme towards F_{MSY} proxy.

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9.12 Future Research and data requirements

The Separable Cohort Analysis is highly dependent of the quality of the length frequency and the life-history parameters, mainly growth and natural mortality. Length–frequency data in FU 30 resulted quite noisy probably due the sampled do not cover the whole the year and the low intensity of individuals sampled. Therefore, there is a need to improve the annual length–frequency distribution. In addition, sex-ratio indicator should be review annually.

Future work should also be carried out in order to improve the knowledge of asymptotic length and k growth parameter in FU 30. Moreover, natural mortality studies should be conducted.

10 Conclusions

For the stocks in FU 23–24 and FU 30, the reviewers conclude that the UWTV survey method, as described in the stock annex is appropriate for providing scientific advice on the abundance of these stocks, Likewise, the amended UWTV survey method for FU 3–4 is appropriate for the same purpose. However, for all these stocks, the reviewers agree that for deriving reference points, and hence translate the stock abundance estimate to recommended removals, the common length-based yield per recruit method is not appropriate. The reviewers agree that deriving harvest rates from historical experience and from experience with similar stocks, as suggested by WKNEP is acceptable as an interim solution, until a firmer basis for generating advice from UWTV survey abundance estimates can be developed.

For FU 32, the reviewers conclude that any reliable assessment is out of reach due to the lack of data. Survey information that was presented may be useful for monitoring purposes.

In relation to the issues surrounding the analytical approach to reference point setting, WKNEP proposed an interim solution, but recommends that ICES establishes a study group to examine methods to derive recommended removals in stocks where the abundance estimate comes from other sources than an analytic assessment. Although *Nephrops* monitored with UWTV surveys perhaps is the most obvious example at present, a study group can have a broader scope.

One of the major drawbacks of the current analytical approach is the equilibrium assumption is made and whilst the use of 3-year averaged length distributions may go some way to removing the effects of strong year classes, these models are unsuitable for the determination of stock status where there are systematic changes in fishing mortality. It was noted at the 2009 *Nephrops* Benchmark that there was some discrepancy between the size of population the cohort models generated compared to the estimates of abundance coming from the TV surveys, but at the time the discrepancies were not considered to be of concern because the LCA was being used to essentially parameterise the selection parameters for a yield-per-recruit analysis and not be an assessment of absolute stock or mortality.

At WKNEP 2016 two new TV surveys were presented, for FU23–24 and FU30 and initial runs of the cohort based models resulted in radically different population estimates compared to the TV abundance (differences of ~5–10 fold), coupled to high estimates of fishing mortality even at times where the fisheries were very small. Reconstructing the total mortality from the length distribution of catches by a Jones cohort analysis indicated fishing mortality at length being very different from the assumed logistic function, however this deviation from model assumption is unlikely to be the sole cause of the difference between population abundance estimates. Although the estimates of population size and fishing mortality from the LCA are not used as measures of stock status, the group felt that these discrepancies were so great that there was a significant risk of the LCA derived estimates of fishery parameters and their associated MSY proxy points being biased.

For many stocks, including *Nephrops*, the stock abundance is monitored by methods that measure the abundance in absolute terms, or have the potential to do so. That includes UWTV surveys for *Nephrops* but also acoustics, egg surveys, tagging and even swept area measures in trawl surveys. Combining such absolute measures with a catch-dependent analytic assessments can lead to conflicts as survey and catches are two competing absolute measures, both with errors and with an uncertain link (natural mortality) between them. Most often, the conflict is avoided by treating survey information as relative. However, that may not be the only way, and there is considerable interest in making more direct use of survey measurements. In all such cases methods will be needed for translating the measured abundance into advice.

At present, solutions have been somewhat *ad hoc*, and the result not always satisfactory. It is suggested that ICES may benefit from establishing firmer standards in this field. Such methods may go beyond length based yield per recruit and include approaches that do not require analytic assessments or models of population dynamics. The suggestion by WKNEP 2016 to consider what harvest rate the stock seems to have tolerated in recent years may be one way forward.

In conclusion, WKNEP 2016 recommends that ICES establishes a study group to examine and propose methods for deriving catch advice from absolute abundance measurements for stocks where there is no analytic assessment. *Nephrops* monitored by UWTV surveys represents the most prominent problem at present, and may be taken as a working example. The group should consider length-based yield per recruit as one approach, but also alternative approaches.

11 Comments from external experts

Comments on the 2016 *Nephrops* Benchmark are offered from the perspective of a review of the information presented on proposed methodology for assessing the stocks and providing input to the advisory process. While there was not adequate time to fully evaluate all data and methodological details, the reviewers scrutinized the presented material and suggested improvements where relevant. A number of comments regarding these are offered below.

Over some years, there has been a development towards UWTV surveys as the main source of information about stock abundance for *Nephrops* in European waters. The present workshop considered that approach for two new stocks, in FU 23–24 and FU 30, and amendment of the existing assessment for FU 3–4. The status of FU 32 was also considered, but any reliable assessment for this stock is out of reach due to the lack of data. FU 28–29 was also scheduled for the present benchmark but had to be postponed to finalize necessary preparatory work.

For each of the stocks with UWTV surveys, the group considered in detail:

- the technology of the survey, including correction for edge effects, discovery rate, species identification, etc.;
- the distribution area and coverage;
- the derivation of a recommended harvest rate.

For all these stocks the WGNEP considered, and the reviewers endorsed, that with regard to the first two bullet points, the UWTV survey-based assessment as described could be standard for the future. When attempting to derive reference points, with what is deemed to be an accepted method for such stocks, unexpected problems were uncovered that could not be solved at the meeting. This is further discussed below.

For FUs 3–4, UWTV surveys have been used for several years to assess the stock, and the present benchmark was mostly to endorse improvements and refinements. The WKNEP agreed that the proposed changes were acceptable.

Some specific issues:

11.1 Reference points

The key reference point for managing a stock with UWTV survey assessment is the recommended harvest rate, as a measure of exploitation. The guidance for that should be a proxy for F_{MSY}, which may be $F_{0.1}$, $F_{35\%SPR}$ or F_{max} if that is sufficiently well defined. The approach, in line with what has been done for other stocks, was to use a length-based steady state population model to obtain yield per recruit. The main tool used was the SCA software, which is a standard length-based equilibrium model with fixed parametric selection that is fitted to the length distribution of the catches. For a number of other stocks, one can simply calculate a yield per recruit from growth and selection parameters and assumed natural mortalities, with what appears to be sensible parameter values according to literature and occasional local observations. These may not be well parameterized, but tend to give reference points that are in line with what would commonly be regarded as reasonable.

For the stocks in FU 23–24 and FU 30, WKNEP compared the abundance estimates from the SCA model with those estimated by the survey, and found large differences.

As a result, harvest rates derived from the SCA lead to much larger recommended catches than experienced historically because of the larger population estimate from the UWTV survey. The problems could be amended to a variable extent in numerous ways, but in particular by increasing the natural mortality in the SCA model, which again would have an impact on the reference points and subsequently on the harvest rate to be recommended.

It was also realized that the length distributions, in particular in FU 30, declined step-wise towards larger length, which would not be compatible with constant growth and mortality for those lengths. Attempts to estimate mortality with the Jones cohort analysis indicated a declining F towards larger lengths for both sexes, although with different patterns, which, assuming a constant natural mortality, violates the assumption of flat selection-at-length. For FU 3–4, two different but similar models were applied (SCA and SLCA) and the results were comparable.

The WKNEP found the issue of poor model fits (assuming M of 0.2 and 0.3) severe enough to preclude a routine application of standard methods, as it was unable to decide on adequate growth and mortality parameters. Results suggested that M should have been higher, for example, in the order of 0.4–0.5. This is not unique to *Nephrops* stocks, and this was reaffirmed here. The model parameters originate from general literature and occasional local observation. To ensure consistent standards, the WKNEP decided to recommend initiating the development of common guidelines for how to derive MSY and precautionary reference points for the exploitation of *Nephrops* that are assessed with UWTV surveys.

The conclusion, which was supported by the reviewers, was to present reference points derived from historical experience from similar previously assessed stocks as an interim solution. While these harvest rates were chosen deliberately on the precautionary side, their application still imply a major increase in landed catch, given that the UWTV surveys currently indicate that both these stocks are lightly exploited. A gradual transition towards higher TACs was recommended, but the exact design of such a regime would have to consider economic and social aspects that are outside the remits of the benchmark group.

Part of the SCA model output is an estimate of the absolute stock abundance. This method gave stock estimates far below those of the UWTV survey. While a reasonable fit could be obtained, the SCA model typically required a higher natural mortality than normally assumed for European *Nephrops* stocks. However, a new length-based methodology has been developed to estimate F and M simultaneously for multiple *Nephrops* stocks. When five *Nephrops* stocks were input into this hierarchical mean length and effort model, new estimates of M were produced for each stock and sex. These results also suggested that higher natural mortalities may be required for four out of five stocks.

Therefore, there clearly are indications that the natural mortality may be higher for some *Nephrops* stocks than previously assumed. However, there is not only uncertainty in the values of natural mortality, but also in the assumed growth parameters and the shape of the length selectivity in the fishery. All of these factors can affect the shape of the catch-at-length distribution, and in the SCA model, can produce different magnitudes of stock abundance.

WKNEP spent some time considering if high Ms on the order of 0.4 and higher could be valid, and in fact, where the original assumption of 0.2 and 0.3 came from. Although a higher natural mortality may be realistic, this requires further validation given that natural mortality is so poorly known. It is recommended that this is done as part of a broader exploration of methods to translate UWTV measured abundance into advice, by harvest rates derived from yield per recruit or by other approaches.

There is also a concern that the higher natural mortality assumption may lead to unwarranted increases in exploitation, as $F_{0.1}$ goes up with a higher M.

11.2 Spatial definition

On some occasions, areas that were not covered by the surveys were identified. It was agreed that if these areas contributed little to the fishery and hence the total stock abundance, then they should be ignored. While this may lead to a small underestimate of the total stock, it would not be unduly restrictive to the fishery. The alternative would be to postpone the transition to UWTV survey assessments, which was not recommended.

11.3 Survey index

In relation to FU 32, the WKNEP requested that estimates of relative biomass be presented at a finer spatial scale. Originally, the index was modelled with Skagerrak and the Norwegian Deep as having combined trends. The index was recreated with the two areas separated, and reviewed by the group. The results from the two runs were similar, but WKNEP concluded that the separated area approach was more appropriate.

11.4 Life-history parameters

It became clear that the uncertainty in life-history parameters (growth, natural mortality) for *Nephrops* is contributing to current model outputs. Therefore, the reviewers suggest future consideration of regionally-specific estimates of growth (specifically von Bertalanffy growth parameters) that reflect local population dynamics. Additionally, results from the hierarchical mean length and effort model suggest that natural mortality can be highly variable for *Nephrops*, and that for several functional units it may be higher than the 0.2 and 0.3 that was previously assumed. Thus, in the future it would be useful to validate natural mortality of *Nephrops* at the functional unit level.

For FU 30, there is some question about sample sizes in the length–frequency distributions, and the data appear to be quite noisy. Given the high dependence of length frequencies in length-based models (the SCA model as well as others), there’s a continued need to ensure appropriate samples as data input.

11.5 Conclusions

For the stocks in FU 23–24 and FU 30, the reviewers conclude that the UWTV survey method, as described in the stock annex is appropriate for providing scientific advice on the abundance of these stocks, Likewise, the amended UWTV survey method for FU 3–4 is appropriate for the same purpose. However, for all these stocks, the reviewers agree that for deriving reference points, and hence translate the stock abundance estimate to recommended removals, the common length based yield per recruit method is not appropriate. The reviewers agree that deriving harvest rates from historical experience and from experience with similar stocks, as suggested by WKNEP is acceptable as an interim solution, until a firmer basis for generating advice from UWTV survey abundance estimates can be developed.

For FU 32, the reviewers conclude that any reliable assessment is out of reach due to the lack of data. Survey information that was presented may be useful for monitoring purposes.

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Annex 2: Working documents

The following working documents were presented at WKNep 2016 and are included in full in the following pages of the report:

General methodology

1) Estimating *Nephrops* mortality from a Bayesian hierarchical mean length and effort model. Liese Carleton.

FU3–4

2) Working document describing the current assessment issues for *Nephrops* in Functional Unit 3 and 4. Jordan P. Feekings.

FU32

3) A model to derive stock indices for *Nephrops* from a trawl survey. Carsten Hvingel, Guldborg Søvik and Ann Merete Hjelset.

FU23–24

4) Coexistence *Nephrops*/Munida. Explorations from the UWTV survey data on the FU23–24 *Nephrops* stock. Spyros Fifas and Michèle Salaun.

5) Study and assessment of the Bay of Biscay *Nephrops* on the basis of UWTV survey. Spyros Fifas, Mathieu Woillez, Michèle Salaun, Jean-Philippe Vacherot.

FU30

6) Analysis of the biological sampling of *Nephrops* FU30 commercial catches. J. Castro, A. Juárez, J.J. Acosta, J.L. Cebrián, M. Marín, E. Velasco, B. Patiño, J. Rodríguez and J. Teruel.

7) Biological parameters in *Nephrops* FU 30 (Gulf of Cadiz). Vila, Y.

8) *Nephrops* (FU 30) UWTV Survey on the Gulf of Cadiz Grounds. Vila, Y., Burgos, C., and Soriano, M.

Estimating *Nephrops* mortality from a Bayesian hierarchical mean length and effort model

Liese Carleton

Introduction

This hierarchical model simultaneously estimates catchability (q) and natural mortality (M) from time series of mean length and effort for multiple stocks of *Nephrops*. This is an extension of the more traditional single stock mean length and effort model (Then et al. submitted). While this is a non-equilibrium estimator, there are several assumptions and key diagnostics to validate that the assumptions have not been violated, some of which will be discussed below.

The key assumptions to this model include:
- growth can be explained perfectly by von Bertalanffy growth parameters
- growth parameters do not change over time
- recruitment is constant or randomly fluctuating over time
- constant q and M over time and age of the fishable population
- knife edge selection where all animals above a certain length are fully vulnerable to the fishing gear

Theoretical Background

The mean length-based mortality estimator developed by Beverton and Holt (1956) estimates total mortality (Z) as:

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L_c}$$

where K and L_∞ are von Bertalanffy growth parameters, L_c is the length at which all animals are vulnerable to the fishery, and $\bar{L}$ is the mean length above L_c.

The Beverton-Holt mortality estimator assumes equilibrium, and Gedamke and Hoenig (2006) extended this estimator to apply it in non-equilibrium scenarios. The Gedamke-Hoenig mortality model estimates Z for a number of periods by modeling the transition period between equilibrium states.

The traditional mean length and effort model extends this by modeling Z over time as a function of effort:

$$Z_t = qf_t + M$$

where f_t is the effort in each year t. Fishing mortality for each year t (F_t) can be calculated as $qf_t = F_t$.

Finally, the hierarchical mean length and effort model uses data from multiple functional units (FUs) to estimate sex-specific distributions of M at the species level, and stock-specific distributions of q that are separated into sex via some multiplier.

Derivation of Hierarchical Model

Population numbers (N) for each stock k and sex s are constructed for each age a by defining that initial numbers at the age of first capture are 1 (due to the assumption of constant recruitment), and then decline exponentially with age and time at a rate of stock- and sex-specific Z via:

$$N_{a+1,t+1,k,s} = N_{a,t,k,s} * e^{-Z_{t,k,s}},$$

where N are the population numbers at age a, year t, stock k, and sex s.

Total mortality for each year t, stock k, and sex s is calculated by:

$$Z_{t,k,s} = q_{k,s} f_{t,k} + M_{k,s}.$$

$M_{k,s}$ is estimated as a random effect where stock-specific M values are drawn from sex-specific lognormal distributions that have some estimated mean M. The priors for the sex-specific mean Ms are based on the previously-assumed natural mortalities of 0.2 (females) and 0.3 (males). The value for $q_{k,\text{male}}$ is estimated as coming from an uninformative lognormal distribution, and is multiplied by some reduction factor to derive $q_{k,\text{female}}$. This formulation of sex-specific q values was chosen because for all *Nephrops* stocks considered in this model, there is either a 1:1 ratio of males to females or the ratio is skewed towards catching more males. Biologically, this is due to females spending more time in burrows, and therefore are less available to the fishery. For more detail regarding formulation of the priors, see Table 1.

Mean lengths at age ($\bar{L}_a$) are calculated via stock- and sex-specific von Bertalanffy growth parameters:

$$\bar{L}_{a,k,s} = L_{\infty_{k,s}} \left(1 - \exp\left(-K_{k,s} * \left(a - t_{0_{k,s}}\right)\right)\right).$$

Predicted mean lengths are then modeled from the age at first capture (a_c) to infinity (or some defined upper limit for maximum age) as follows:

$$\bar{L}_{pred_{t,k,s}} = \frac{\sum_{a=a_{c_{k,s}}}^{\infty} (\bar{L}_{a,t,k,s} * \hat{N}_{a,t,k,s})}{\sum_{a=a_{c_{k,s}}}^{\infty} \hat{N}_{a,t,k,s}}.$$

The likelihood for fitting the predicted mean lengths to the observations is set up such that $\bar{L}_{t,k,s} \sim \text{Normal}(\bar{L}_{pred_{t,k,s}}, n_t * \tau_{\bar{L}_k})$, or the observed mean length is drawn from a normal distribution with a mean of the prediction and a precision that is a function of the sample size and the estimated stock sampling precision.

Model Specifics

The hierarchical mean length and effort model was run in JAGS, which uses Gibbs sampling of the Markov Chain Monte Carlo (MCMC) algorithm, using the R2Jags package for R (R Development Core Team, 2016; Su and Yajima 2014). This model ran using two MCMC chains with 100,000 iterations, a burn-in period of 10,000, with a thin of 5 to reduce auto-correlation. This number of iterations resulted in convergence of the MCMC chains, as determined by visually examining Gelman-Rubin plots and diagnostics (Gelman and Rubin 1992). All potential scale reduction factors ($\hat{R}$) were far below the threshold of 1.1.

During model development, the appropriateness of the priors was evaluated by comparing different model iterations using the deviance information criterion (DIC) (Lunn et al. 2013). Additionally, prior and posterior distributions were examined to ensure that parameters were not stuck against the bounds, which evaluates the appropriateness of the overall model structure.

Data Specifics

Data from five *Nephrops* stocks were used in this model, specifically data from functional units 3-4, 23-24, 28-29, 30, and 31. For all stocks, fishing effort in years prior to the time series was assumed to be equal to the effort of the first year of data. Annual commercial catch length frequency distributions (which includes landings and dead discards) for each stock and sex were examined to ensure that there were no trends in recruitment over the time series. A recruitment trend would present itself if peaks were seen to move to the right as you step forward each year. L_c was determined for each stock and sex typically as the peak of the length frequency distribution when pooled over all years. If the peak was driven by one or two years of data, then L_c was chosen as a secondary peak to the right. A summary of the growth and vulnerability parameters can be found in Table 2.

Model Results and Discussion

Examination of the posterior densities of these parameters (Fig. 1) show that these parameters are not against any bounds and have been defined appropriately.

In general, the model predictions fit the observed mean lengths fairly well (Fig. 2). Residuals are a key diagnostic tool when using the mean length and effort model. For example, FU 23-24 have residuals that appear to decline over time for both sexes. This could indicate a trend in recruitment, which means that the change in mean length may not be explained by the change in effort. The large residuals in FU 31 toward the end of the time series can be explained by the relatively large L_c, which restricts the length frequency data that are used to calculate mean length, making these data more sensitive to outliers.

A summary of the estimated *M* and *q* parameters can be seen in Table 3. The estimated *q* values are also presented, although these numbers depend on the scale of the effort data. A better understanding of the estimated *q* values can be gained by looking at the estimates of fishing mortality (Fig. 3), which are relatively low compared to the estimated natural mortalities. Additionally, the relatively high degree of uncertainty in *q* (as evidenced by the large 95% CI) results in a large range of credible fishing mortalities.

In general, the hierarchical mean length and effort model produced values of *M* that were much more variable among functional units than were previously assumed for *Nephrops*. In several cases, *M* was estimated to be fairly high, with corresponding low *F*s. Given the fairly uninformative priors in the model, these high *M*s appear to be driven by the data. However, there is an interplay between mortality, recruitment, fishery selectivity, and growth parameters, and so it’s important to examine model assumptions. Assigning continuous growth to a molting species clearly will have some ramifications, but perhaps more serious a flaw is the uncertainty in the growth parameters, as few age determination studies have been done for *Nephrops*.

Table 1 Description of both estimated and derived parameters and their priors.

Estimated Parameters		
Parameter	**Description**	**Prior**
$M_{k,s}$	Natural mortality for each stock and sex	Lognormal(Log $\bar{M}_s$, τ_{M_S}) *Note that these parameters are corrected log mean and corrected log precision
Log $\bar{M}_{\text{male}}$	Log of the mean natural mortality for males	Lognormal(-1.42, 2.26) *Has mean of 0.3, variance of 0.05
Log $\bar{M}_{\text{female}}$	Log of the mean natural mortality for females	Lognormal(-2.01, 1.23) *Has mean of 0.2, variance of 0.05
τ_{M_s}	Precision of natural mortality for each sex	Gamma(0.1, 0.1) *uninformative
$q_{k,\text{male}}$	Catchability for males of each stock	Lognormal(-2.65, 1.44) *uninformative
C_k	Stock-specific fraction of females caught for every male	Uniform(0.3, 1.1)
$\tau_{\bar{L}_k}$	Precision of mean length for each stock	Gamma(0.001, 0.001) *uninformative
Derived Parameters		
Parameter	**Description**	**Derivation**
$q_{k,\text{female}}$	Catchability for females of each stock	$q_{k,\text{female}} = C_k * q_{k,\text{male}}$

Table 2 Von Bertallanfy growth parameters and length at 100% vulnerability that were input in the model for each stock and sex.

Stock	**Sex**	$\boldsymbol{K}$	$\boldsymbol{L_\infty}$	$\boldsymbol{L_c}$
FU 3-4	M	0.138	73	40.5
	F	0.1	65	40.5
FU 23-24	M	0.14	76	25.5
	F	0.11	56	25.5
FU 28-29	M	0.2	70	32.5
	F	0.065	65	32.5
FU 30	M	0.2	60	33.5
	F	0.065	60	34.5
FU 31	M	0.16	70	40.5
	F	0.08	60	40.5

Table 3 Model estimates of means and 95% credible intervals for stock- and sex-specific *M* and *q* parameters.

Stock	**Sex**	***M*** Mean (95% credible interval)	***q*** Mean (95% credible interval)
FU 23-24	M	0.70	0.023

		(0.58, 0.8)	(0.007, 0.047)
	F	0.51 (0.4, 0.61)	0.015 (0.004, 0.034)
FU 28-29	M	0.38 (0.29, 0.46)	0.022 (0.007, 0.044)
	F	0.24 (0.17, 0.3)	0.013 (0.003, 0.028)
FU 30	M	0.47 (0.34, 0.58)	0.0072 (0.003, 0.013)
	F	0.36 (0.24, 0.48)	0.0053 (0.002, 0.011)
FU 31	M	0.14 (0.1, 0.18)	0.0018 (0.001, 0.003)
	F	0.08 (0.05, 0.11)	0.00081 (0.0004, 0.0015)
FU 3-4	M	0.51 (0.41, 0.59)	0.064 (0.012, 0.177)
	F	0.37 (0.3, 0.44)	0.040 (0.007, 0.113)

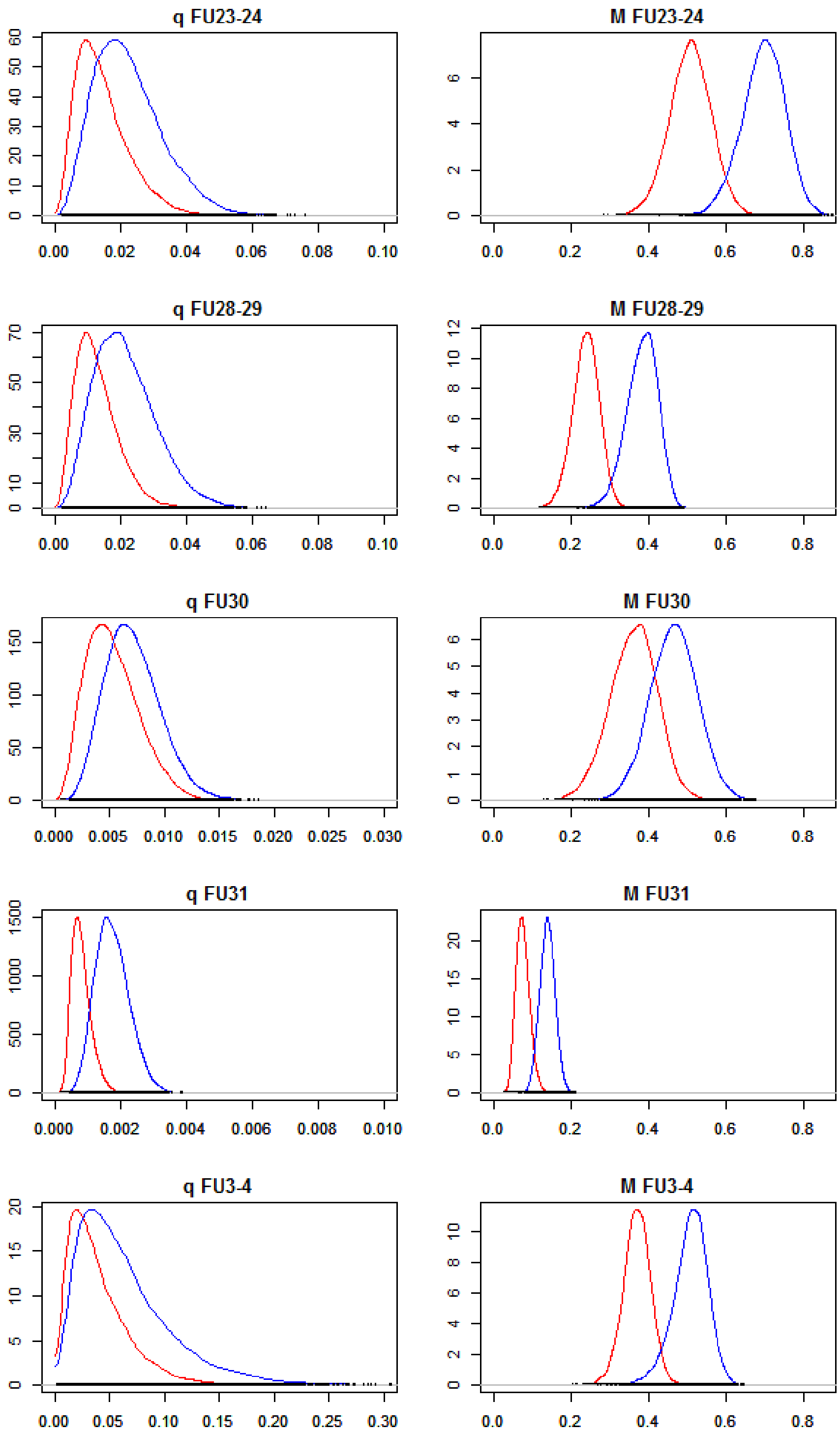

Fig. 1 Estimated posterior densities for q (left) and M (right) for each of the five stocks. Red represents females, blue represents males.

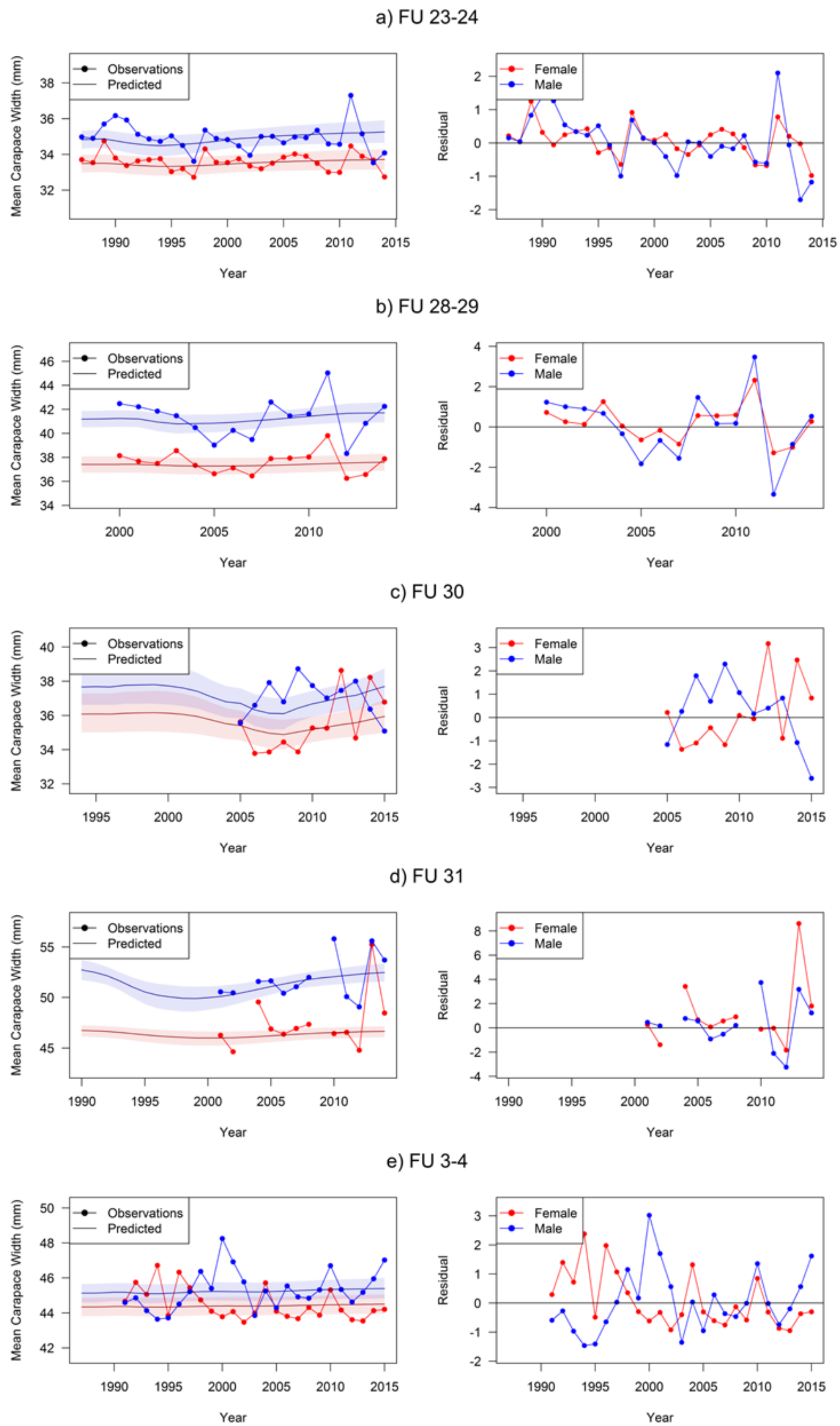

Fig. 2 Predicted and observed mean lengths for each stock and sex, surrounded by 95% credible interval (left), and residuals (right). Red represents female, blue represents male.

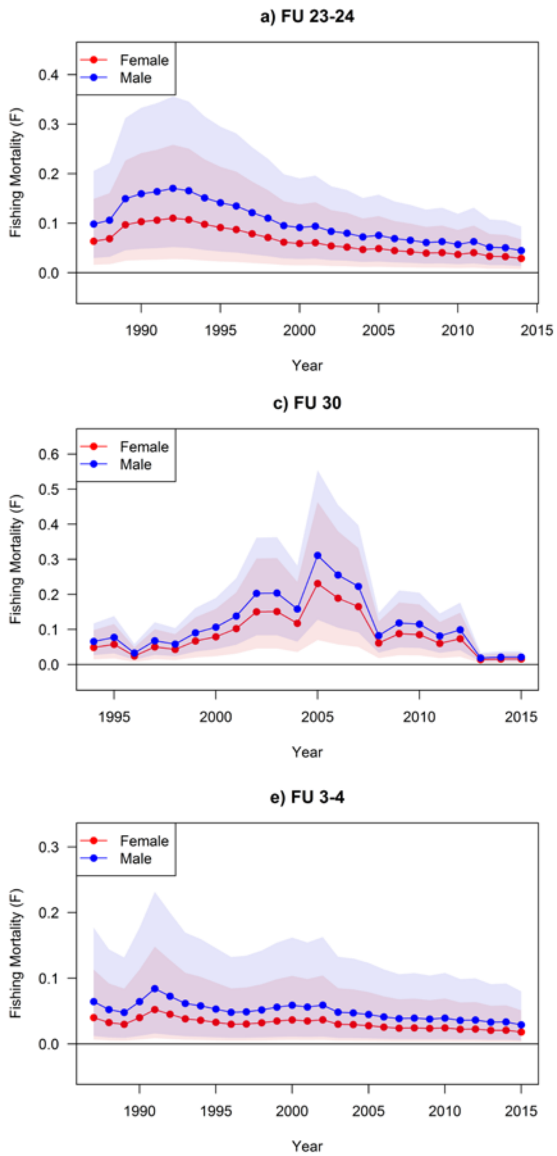

Fig. 3 Estimated fishing mortalities, mean surrounded by 95% credible interval, by stock (panel) and sex (color), as calculated by $F_{k,s,t} = q_{k,s} * f_{k,t}$.

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Working document describing the current assessment issues for *Nephrops* in Functional Unit 3 and 4

The current assessment of Norway lobster (*Nephrops norvegicus*) in the Skagerrak and Kattegat (Functional Units 3 and 4) consists of an Underwater TV (UWTV) survey. Additional information used in the assessment includes trends in total combined (Denmark and Sweden) LPUE, and discards (numbers) as a proxy for recruitment. The three issues to be resolved as part of the current benchmark for FU 3 and 4 are introduced below.

Assessment issue number 1

The UWTV survey of *Nephrops* in FU 3 and 4 has been conducted by Denmark since 2008 and by Sweden since 2010 but was first used as part of the analytical assessment in 2011. The initial surveys (2008-2009) only covered a limited spatial extent of the fishery (Subareas 1 and 2) and were therefore considered exploratory. The spatial extent of the survey was expanded in 2010 to cover the main *Nephrops* fishing grounds. VMS data from the Swedish and Danish fishery were coupled with landings from the official logbooks to define the spatial extent of the fishery. However, the borders of the fishing grounds were arbitrarily defined which led to the recommendation (SGNEPS, 2010) to employ a less subjective method to estimate the area boundaries of the stratified survey areas.

Assessment issue number 2

Underwater techniques targeted to estimating the abundance of *Nephrops* are based on the identification and quantification of their burrows. This technique provides fishery independent estimates which are not affected by the differences in the daily and seasonal emergence pattern of the specie. The quantification of burrows from UWTV recordings is carried out by people who are experienced in the identification of burrowing fauna, whereby two of more counters count each station consisting of 7 minutes. To help ensure counters are counting equally as good as in previous years, it is recommended that a set of reference footage be created for each functional unit (assessment issue number 2). The objective of the reference set is to provide pre-survey training and standardization of counter's performance before being given access to the current survey footage.

Assessment issue number 3

The current Length Cohort Analysis (LCA) is based on length frequency data from 2008-2010 and assumes a discard survival of 25 %. Furthermore, the Minimum Landing Size for *Nephrops* in FU 3 & 4 was reduced in the beginning of 2016 from 40 to 32 mm carapace length. Based on new discard survival estimates for FU 3 & 4, an updated length frequency and a new MLS the length cohort analysis needed to be updated.

Redefining the spatial distribution of *Nephrops* in functional unit 3&4

The spatial distribution of the *Nephrops* fishing grounds in the Skagerrak and Kattegat (Functional units 3 & 4) were previously defined using Danish and Swedish VMS data from 2010, whereby the borders of the fishing grounds were arbitrarily defined in ArcGIS (Figure 1). In 2011, a grid-based survey design was introduced and some of the outer fishing grounds were dropped from the survey area.

In 2010 the spatial extent of the UWTV survey was expanded to cover all main fishing grounds. VMS data from the Swedish and Danish fishery were used, providing VMS position for almost every hour and filtered on vessel speeds between 2 and 4 knot as a proxy for fishing activity. These are naturally restricted to vessels above 15 meters as vessels below this size are note part of the VMS scheme. The VMS data was combined with official logbooks information to extract only trips targeting Nephrops (with a minimum 50% of Nephrops of the total landings). These trips represented ~ 80% of the total landings of vessels above 15 meters.

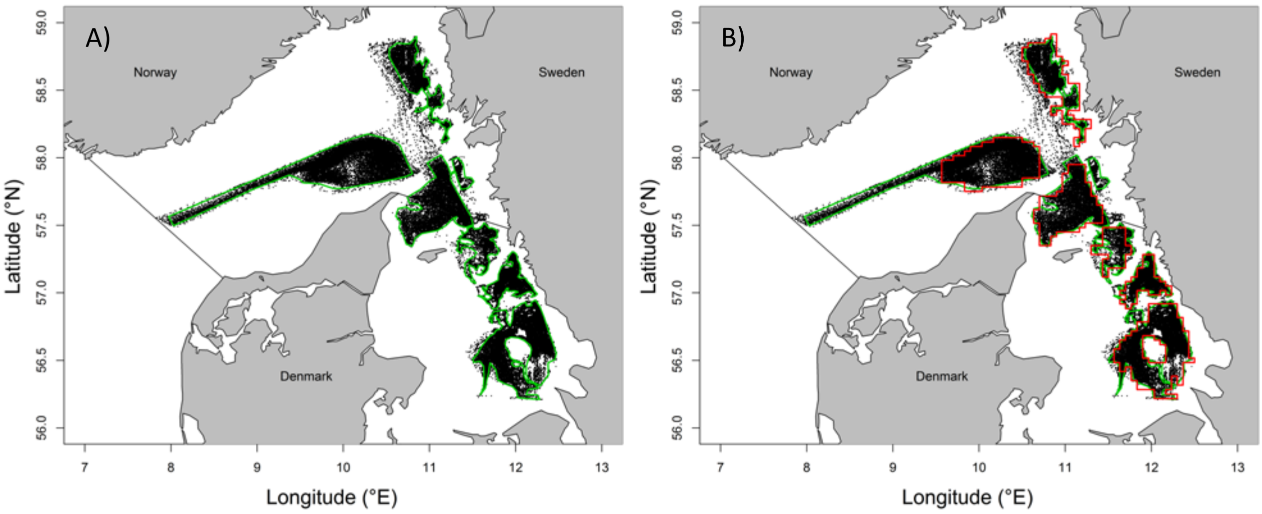


Figure 1A and B. Spatial distribution of the *Nephrops* fishing grounds as previously defined (1A) and as defined in the grid-based survey design (1B).

Due to additional data becoming available (VMS data 2005-2015 and sediment maps) as well as some key areas not being included in the current spatial distribution (E.g. Swedish creel fishery) it was decided to develop a more accurate estimate of the spatial extent of the *Nephrops* fishery in the Skagerrak and Kattegat.

Based on historical VMS and landings data (2005-2015) from Denmark and Sweden, logbook and observer data for the Swedish creel fishery, together with sediment type and bathymetric data, the spatial distribution of the *Nephrops* grounds in the Skagerrak and Kattegat will be redefined following the methodology described below.

The current grid based design will be retained, possibly using a disaggregated grid to define the spatial extent of the fishery. Based on the updated population estimates retrospectively based on the new area estimate.

1. Filter out the VMS data based on
   - Speed. Remove speeds below 1.8 and above 3.0 knots
   - Metier type. Keep only those metiers targeting Nephrops (Demersal trawls with a mesh size greater than 70 mm. E.g. OTB_CRU, OTB_MCD, OTB_DEF, OTT_CRU, OTT_MCD, OTT_DEF)
   - Proportion of Nephrops in the catch
     - 5 % *Nephrops* in the catch
     - 10 % *Nephrops* in the catch
     - 20 % *Nephrops* in the catch
     - 30 % *Nephrops* in the catch
2. Define the spatial limits of the subareas based on the amount of effort in a cell using different cut-off points. For example:
   - minimum of 10 hours fishing
   - minimum of 20 hours fishing
   - 95 % of the total effort
   - 90 % of the total effort
3. Overlay the VMS defined fishing grounds with the available substrate maps to define each cell's mud content and use the mud content in each cell to refine the area estimate.

Data to include

4. Danish and Swedish VMS data 2005-2015
5. logbook and observer data for the Swedish creel fishery
6. Sediment and bathymetric data
7. Swedish logbook data

Text taken from the CRR document

Defining the spatial extent of the suitable habitat for *Nephrops* is used to raise the observed density estimates to total stock biomass. Therefore, the assumed spatial extent of the suitable habitat can cause large differences in stock biomass estimates depending on what data are used to calculate the spatial extent.

Owing to its burrowing behaviour, the distribution of *Nephrops* is restricted to areas of mud, sandy mud and muddy sand. Therefore, the spatial extent of *Nephrops* habitats has historically been defined based on the spatial extent of the suitable sediment types and logbook information???. The introduction of vessel monitoring systems (VMS) has provided a more accurate representation of the extent of the fishery. However, the accuracy of the currently used boundaries of what is considered *Nephrops* suitable habitat has been considered a source of uncertainty by WKNEPH (ICES, 2006; ICES, 2009) particularly in highly heterogeneous grounds where differences between fished area, surveyed area and population area are likely to exist.

Using VMS data may provide a better predictor of *Nephrops* distribution than sediment data alone. VMS data 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. The inclusion of VMS data for vessels smaller than 15 meters, which have become available from 2012 onwards, will provide a better picture of the effort distribution in some of the inshore locations corresponding to smaller trawlers and creel boats fishing for *Nephrops*.

Due to VMS data not covering the entire fishery, logbook and at-sea-sampling data can be used as an additional source of information to determine the spatial extent of *Nephrops* suitable habitats. For example, logbook data can be used to determine whether the spatial extent of the VMS covered vessels is different from the spatial extent of the vessels which do not have VMS recordings.

Multibeam data has been collected for several functional units. While such data cannot presently be used to define the spatial extent, seeing as it does not cover the entire survey area, it can be used to verify the extent of suitable habitat.

Validation of, and modification to survey areas from incorporation of additional and/or improved data is something that needs to occur on a regular basis when data becomes available. All available data should be used to define the spatial extent of *Nephrops* suitable habitats. Survey boundaries should be re-examined according to VMS information and updated when new VMS data, or additional data becomes available.

The methods used to define the spatial extent differ across functional units and are dependent on the data available and the heterogeneity in sediment type. Areas consisting of heterogeneous sediment types, such as FU3-4 and FU11 are characterized by numerous islands and sediment types, resulting in patchiness in the spatial extent of the habitable sediment type and distribution of the fishery.

Stratified random (Scotland, FU3&4), Fixed Station (FU6, FU14, FU5, FU34), Fixed grids (pros, cons), Isometric randomized grids (Irish) (SGNEPS, 2012)

Various labs to describe their designs

Survey design

FU 3&4 (Skagerrak and Kattegat)

The survey is conducted in cooperation between Denmark and Sweden since 2011. Following some exploratory technical work in the years 2008 to 2010 by Denmark, 7 subareas were identified mainly based on VMS data, and elements with an isometric spacing of 2 nmi were defined (Fig. xx). From these elements a random number is selected for each subarea separately, and the total numbers of station depends on the available ship time, which currently 15 days for each countries. The number of stations allocated to each subarea followed logistic reasons, e.g. distance to the nearest harbour, since the survey is carried out with small vessels (15 m length) and with a staff of only 2-3 persons in total. From 2014 onwards, however, the station allocation to the various subareas will be based on the variability observed in the preceding years (Fig. xx), and the survey can then be considered as a stratified random survey although the actual definition of the subarea boundaries is to some extent still a bit arbitrary and may not necessarily reflect true strata of abundance.

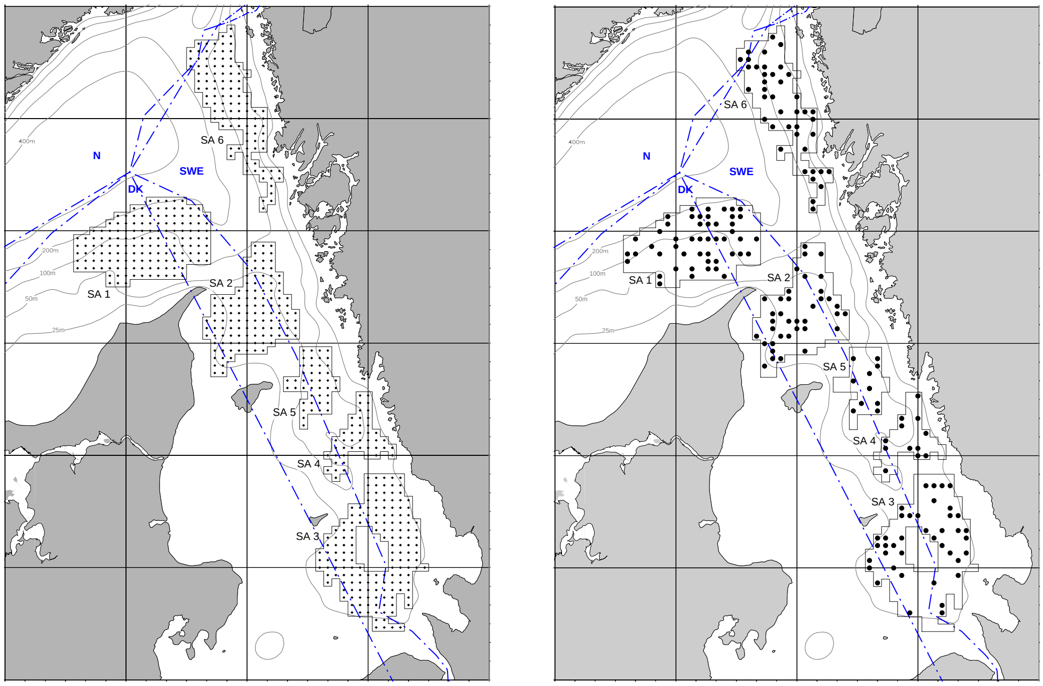


Fig. xx. Survey area and subareas in the joint Danish and Swedish UWTV survey in the Skagerrak and Kattegat (FU 3 & 4) since 2011 and station allocation for 2014.

Create UWTV survey reference footage

In 2015 WGNEPS recommended that a set of reference footage should be established for the Danish/Swedish Underwater TV (UWTV) survey in the Skagerrak and Kattegat (Function Units 3 & 4). To date, a set of reference footage for FU 3 & 4 has not been compiled due to updating of equipment on the Danish sledge.

The objective of a set of reference footage is to provide pre-survey training and standardization of counter's performance. All counters are to count the reference footage to a predetermined standard before being given access to the current survey footage.

At WKNEPHBID 2008 it was decided that a reference set should be comprised of 10 stations of 5 minutes and covering the range of usable video footage encountered on a typical survey. The selected stations should consist of different water qualities (clear to murky waters); high to low densities; and if available a mix of *Nephrops* and other species burrows.

A selection of stations from the 2015 Danish UWTV survey which adhered to the requirements outlined in the WKNEPHBID 2008 report were collated for a workshop. The workshop was held in Lysekil, Sweden 21-23rd Sept 2016 where the most experienced counters from each of the two institutes – SLU (Sweden) and DTU Aqua (Denmark) created the reference counts for FU 3 & 4. The chosen stations consisted of 4 high density (of varying visual clarity; 2 stations good, 1 station ok and 1 poor visual clarity), 3 moderate density, and 3 low density stations. As standard practice, *Nephrops* burrow counts were recorded for each minute of each station.

Each counter reviewed all the footage in isolation and only once all the reference sets had been reviewed were the results compared. The counts for FU 3 & 4 were compared following the same principles outlined for other functional units (Fladen and Farn Deeps (FU 7 and 6 respectively).

Where differences between the counters reached a set threshold the footage for that minute was re-examined and a consensus between the counters was reached for that particular minute. The acceptance criterion for FU 3 & 4 was as follows:

> For a reference count of greater than 20 burrows per minute, counts more than 10% different from the mean were deemed unacceptable. For counts between 15 and 20 the criteria used was 20%, for counts between 9 and 14 the criteria was 30% and for 8 or less it was 40%. For all average counts of 1 or less it was decided there needed to be exact consensus.

The differences in the initial individual counts obtained for each of the stations was above the defined threshold for all bar one station (Table 1). Therefore, the four counters reread the reference material defining how to identify *Nephrops* burrows (WKNEPBID, 2008) and then reread all stations. The reference counts for each station were taken as an average per minute of the four counters. Reference counts by minute and station are shown in Figure 1 and the final consensus counts by station and counter are given in Table 2.

Table 1. Initial counts (average number of burrows per minute) by station (10 x 5 minute run per FU) and counter.

Functional Unit 3 & 4						
Station	Counter 1	Counter 2	Counter 3	Counter 4	Consensus count	Difference (%)
1	2.6	3.8	1.8	1.8	2.5	80
2	6	7.4	3.8	4.8	5.5	65
3	3	4.2	0.6	1	2.2	164
4	7.2	6.2	2.4	1.2	4.3	141
5	6	7	1.8	3	4.5	117
6	12	17.6	12.4	15	14.3	39
7	11.8	11.6	11.4	11	11.5	7
8	5.6	7.8	4.4	4.2	5.5	65
9	20.4	17.8	26.8	24.4	22.4	40
10	9.6	12.8	9.4	10	10.5	33

Table 2. Average counts (number of burrows per minute) by station (10 x 5 minute run per FU) and counter.

Functional Unit 3 & 4						
Station	Counter 1	Counter 2	Counter 3	Counter 4	Consensus count	Difference (%)
1	2	2	1.8	1.8	1.9	11
2	4.8	4.8	4.6	4.6	4.7	4
3	1	0.8	0.8	0.8	0.9	24
4	1.8	0.6	1.2	1	1.2	104
5	3.8	3.4	2.8	3.4	3.4	30
6	13	12.8	12.8	13	12.9	2
7	11.8	11.6	11.4	11	11.5	7
8	4.4	4.2	4.2	4.2	4.3	5
9	32	31.8	32	31.4	31.8	2
10	10.8	10	10	9.8	10.2	10

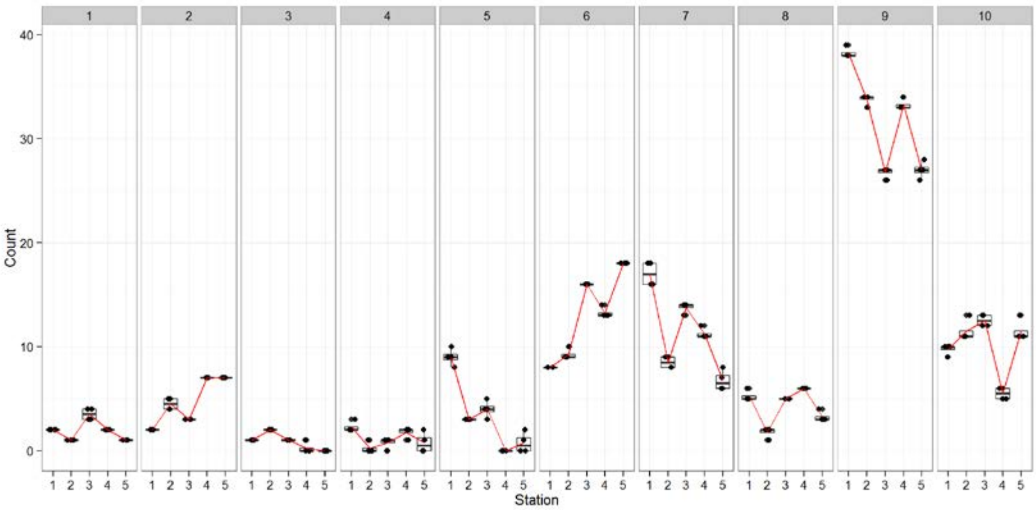


Figure 1. Boxplots of individual burrow counts and mean count (red line) by minute and station for FU 3&4.

Lin's Concordance Correlation Coefficient (CCC) (Lin, 1989) was used to measure the ability of counters to exactly reproduce the reference counts on a scale of 1 to –1 where 1 is perfect concordance (i.e. a pairwise plot will have all points lying along the 1:1 line. A value of –1 would be generated by all points lying on the –1:1 line and a value of 0 indicates no correspondence at all. The CCC values obtained for the counters should all be higher than 0.5. The robustness of this measure is obviously a function of the number of data points and with only 5 points per individual station it was likely that there would be a large degree of scatter. The CCC was calculated for all pairwise combinations of stations (Figure 2). The CCC values obtained were all above the cutoff limit of 0.5 (Figure 3). However, for very low counts (i.e. <2 per minute), small differences (i.e. 1 or 2) in counting have a substantial effect upon the CCC values. Figure 2 shows the CCC values per station, where station 4 displayed the lowest CCC values due to large difference in counts as a result of the low number of burrows observed. The CCC values obtained from each of the 4 counters indicated that all had a good ability to reproduce the reference counts (Figure 4).

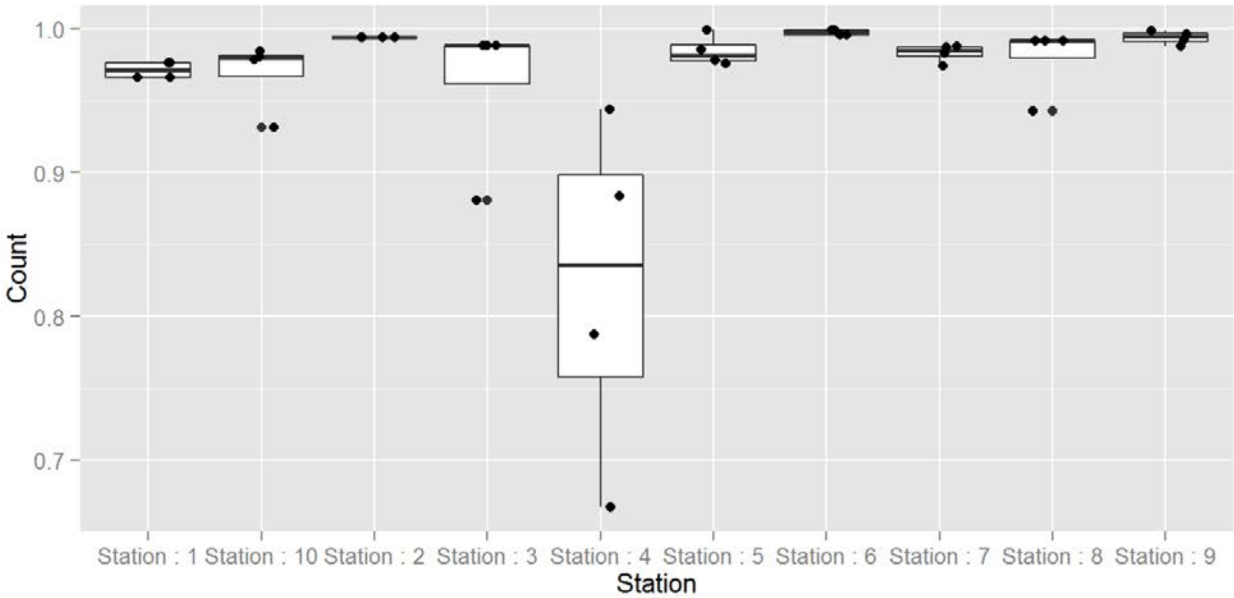


Figure 2. Boxplot of Lin's CCC values per station. Black dots represent observed counts.

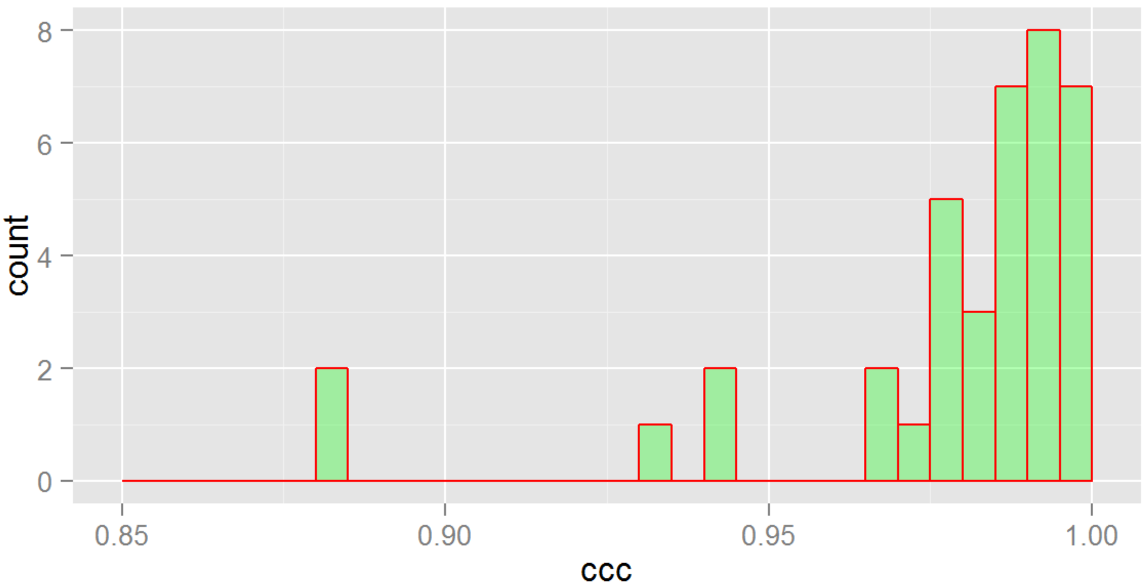


Figure 3. Histogram of Lin's CCC values.

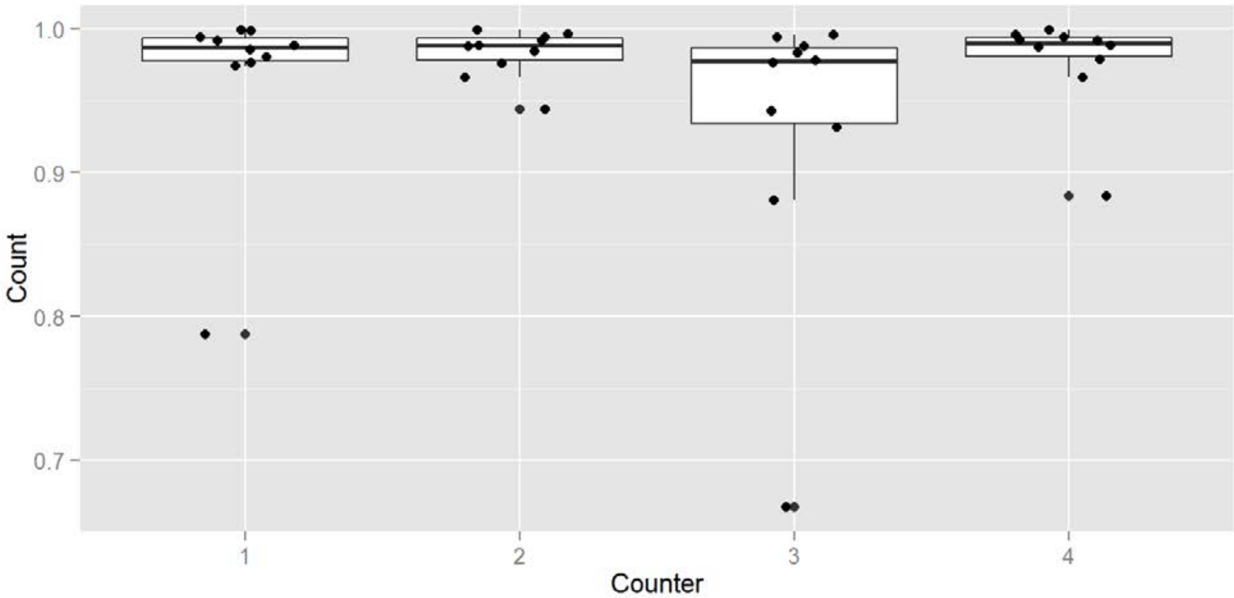


Figure 4. Boxplot of Lin's CCC values per counter. Black dots represent observed counts.

Update Separable Length Cohort Analysis (SLCA)

The current Separable Length Cohort Analysis (SLCA) is based on length frequency data from 2008-2010 and assumes a discard survival of 25 %. Furthermore, the Minimum Landing Size for *Nephrops* in FU 3 & 4 was reduced in the beginning of 2016 from 40 to 32 mm carapace length (CL). Based on new discard survival estimates for FU 3 & 4, an updated length frequency and a new MCS the SLCA needed to be updated.

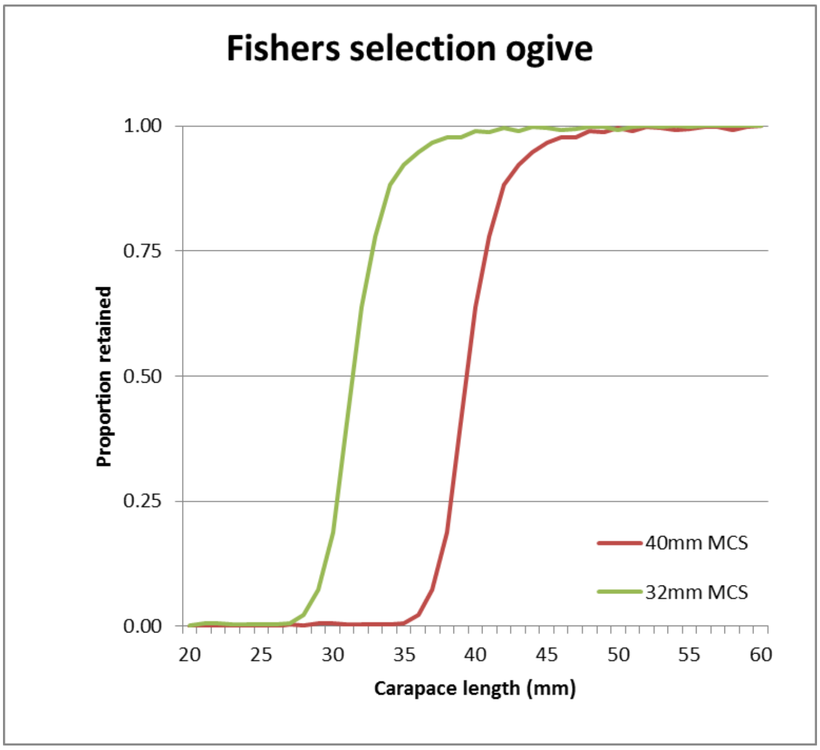
Length frequency data

Length frequency data previously used in the SLCA were from 2008-2010. These data consisted of landings and discards from Danish and Swedish discard observer trips and raised to the total catch in FU 3 & 4. In the updated SLCA Danish and Swedish discard observer trips from 2013-2015 were used.

Minimum Landing Size (MLS)/Minimum Conservation Size (MCS)

The MLSs for Norway lobster (*Nephrops norvegicus*) in European waters are very different and their reasoning's not very well known or documented. In the Skagerrak and Kattegat, the MLS for Norway lobster is 40 mm carapace length (CL), which is considerably higher than in neighbouring areas; 25 mm in the North sea and 20 mm in the Irish Sea. The large MLS in the Skagerrak and Kattegat is the result of a historical regulation that has been maintained following advice from the industry (Eggert and Ulmestrand, 2000; ICES, 2015).

Based on advice to National ministries in Denmark and Sweden the MLS/MCS was lowered from 40 mm CL (130 mm total length) to 32 mm CL (105 mm total length) as of the 1st January 2016 (Norway still applies an MCS of 40 mm CL, however landings account for approximately 3 % of the total landings). Consequently, the proportion of the catch discarded will be greatly reduced. To simulate the effect of a decreased MCS on the proportion discarded, the average (2013–2015) total sampled length distribution (Figure below) was first used to estimate fisher's selection when sorting the catch at a MCS of 40 mm carapace length (red line in graph below). This selection ogive was then shifted down to 32 mm MCRS (assuming that fishers selection is equally effective at the new MCS) in order to predict the new composition of landings and discards. The mean weight in discards (20.5g) and landings (46.2g) and proportion discarded (12.5 %), assuming a MCS of 32 mm was used to populate the SLCA.



Survival rate

The discard survival rate used for *Nephrops* in Functional Unit 3 & 4 is 25 %. This has been based on studies by Gueguen & Charuau (1975), Redant & Polet (1994), and Wileman et al. (1999). In 2015, SLU carried out an experiment designed to estimate the effects of seasonality and the gear used on survivability of discarded Norway lobster (*Nephrops norvegicus* L.) in the three main Swedish *Nephrops* fisheries. The experiment was performed during March and September 2015.

For *Nephrops* caught with a Swedish GRID trawl or a SELTRA trawl, discard survival was 75 % and 59 % respectively in the experiment conducted in March 2015. Discard survival differed significantly between the two trawl types. Survival was significantly lower in September with 42 % for GRID and 38 % for SELTRA. The March survival estimates are in the higher end of previously reported work, while the September ones are more in line with earlier studies. Survival of discarded creel caught *Nephrops* (used as a control) did not differ between the two experiments (98 % in March and 95 % in September).

The combined estimate of discard survivability for all Swedish fleets operating in the Skagerrak and Kattegat, based on the current findings, is 55 %. This estimate does not include post-discard mortality (e.g. predation and discarding on unsuitable bottom types), escape mortality, and black landings. Furthermore, the haul durations in the experiment were approximately 4 hours while the average hauls durations observed in the Swedish and Danish *Nephrops* fisheries are approximately 5 and 6 hours respectively. This may lead to higher than expected survival estimates due to smaller catches, shorter durations in the trawl, and short handling times on deck. Of further interest are the results from Harris and Ulmestrand (2004) who found that discarding *Nephrops* through low salinity surface waters reduces the chances of survival by approximately 30 %. Based on these additional sources of mortality an estimated survival rate of 50 % is possibly an overestimation of discard survival.

Now that the MCS has been reduced from 40 to 32 mm CL the number of individuals which will be discarded will be considerably reduced. Therefore, the issue of discard survival is of lesser concern than previously.

In the SLCA we have looked at three different levels of discard survival; 0, 25, and 50 %. Zero percent was included due to the obligation to land all catches as part of the new CFP. Currently there is an exemption to land all catches, however this is to be revised at the end of 2016. If the exemption from the landing obligation remains a discard survival of 25 % recommended to be used. If the exemption is removed a discard survival of 0 % is to be used.

		Burrow density (average burrows m−2)		
		Low	Medium	High
		<0.3	0.3-0.8	>0.8
Observed harvest rate or landings compared to stock status	> Fmax	F35%SPR	Fmax	Fmax
	Fmax - F0.1	F0.1	F35%SPR	Fmax
	< F0.1	F0.1	F0.1	F35%SPR
	Unknown	F0.1	F35%SPR	F35%SPR
Stock size estimates	Variable	F0.1	F0.1	F35%
	Stable	F0.1	F35%SPR	Fmax
Knowledge of biological parameters	Poor	F0.1	F0.1	F35%SPR
	Good	F35%SPR	F35%SPR	Fmax
Fishery history	Stable spatially and temporally	F35%SPR	F35%SPR	Fmax
	Sporadic	F0.1	F0.1	F35%SPR
	Developing	F0.1	F35%SPR	F35%SPR

Figure xx. The decision-making framework used in the selection of preliminary stock-specific FMSY proxies (ICES, 2010a).

MSY consideration (TV-survey)

There are no precautionary reference points defined for *Nephrops*. Under the ICES MSY framework, exploitation rates which are likely to generate high long-term yields (and low probability of stock overfishing) have been explored and proposed for Division 3.a. Owing to the way *Nephrops* are assessed, it is not possible to estimate F_{MSY} directly and hence proxies for F_{MSY} are determined. WGNSSK (2010) developed a framework for proposing F_{MSY} proxies for the various *Nephrops* stocks based upon their biological and historical characteristics, and is described in section 1 of that report. 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 in many stocks. To account for this, values for each of the candidates have been determined for males, females and the two sexes combined. An appropriate F_{MSY} candidate has been selected 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 (ICES, 2010a). These proxies may be modified following further data exploration and analysis. The combined sex F_{MSY} proxy should be considered appropriate if the resulting percentage of virgin spawner-per-recruit for males or females does not fall below 20%. When this does happen a more conservative sex-specific F_{MSY} proxy should be picked instead of the combined proxy.

A mismatch between mesh size in trawl fisheries and minimum landing size (carapace length 40 mm, which is higher than North Sea FUs) has historically resulted in a high discard proportion for this stock. However, since 1st January 2016 the MCRS/MLS was lowered from 40 to 32 mm carapace length for EU countries. This is expected to reduce the proportion of the catch discarded considerably. Norway still apply 40 mm MCRS and a Norwegian discard ban was implemented in the Skagerrak since 1st of January 2015.

To simulate the effect of a decreased MCRS on the proportion of discards, the average (2013–2015) total sampled length distribution (graph left below) was first used to estimate fisher's selection when sorting the catch at a MCRS of 40 mm carapace length (red line in middle graph below). This selection ogive was then shifted down to 32 mm MCRS (assuming that fishers selection is equally effective at the new MCRS) in order to predict the new composition of landings and discards (see graph right below). The following mean weight in discards and landings, discard proportion and dead discard rate was used in this year's assessment.

Harvest rate as proxy for F_{MSY} for 3.a from length cohort analysis 2011 (2008–2010):

	MALE	FEMALE	COMBINED
Fmax	6.8 %	10.0 %	7.9 %
F0.1	4.9 %	7.6 %	5.6 %
F35%SpR	8.1 %	12.9 %	10.5 %

The harvest rates ((landings + dead discards)/total stock biomass) equivalent to F_{msy} proxies are based on yield-per-recruit analyses from length cohort analyses. These analyses utilise average length frequency data taken over the 3 year period (2008–2010). All F_{MSY} proxy harvest rate values are considered preliminary and may be modified following further data exploration and analysis.

The current LCA is based on length frequency data from 2008-2010 and assumes a discard survival of 25 %.

Based on new discard survival estimates for FU 3 & 4, additional biological data (growth and length-weight data) and a lowering of the minimum landing size (MLS; Minimum Conservation Reference Size (MCRS)) from 40 mm carapace length to 32 mm the length cohort analysis needs to be updated.

2013-2015 length frequency

IIIa Nephrops LCA and harvest rates – sensitivity to discard survival

LCA input data:

Length frequency distribution of dead removals by sex – this is landings + p x discards where p = 0, 0.25 or 0.5 depending on the assumption of discard survival

Length frequency distribution of dead discards (combined sex)

Data averaged over 2013-15.

Discard rates are now very low which is in contrast to the previous analysis conducted in 2011 and 2015 (?). Presumably this is due to the change in MLS.

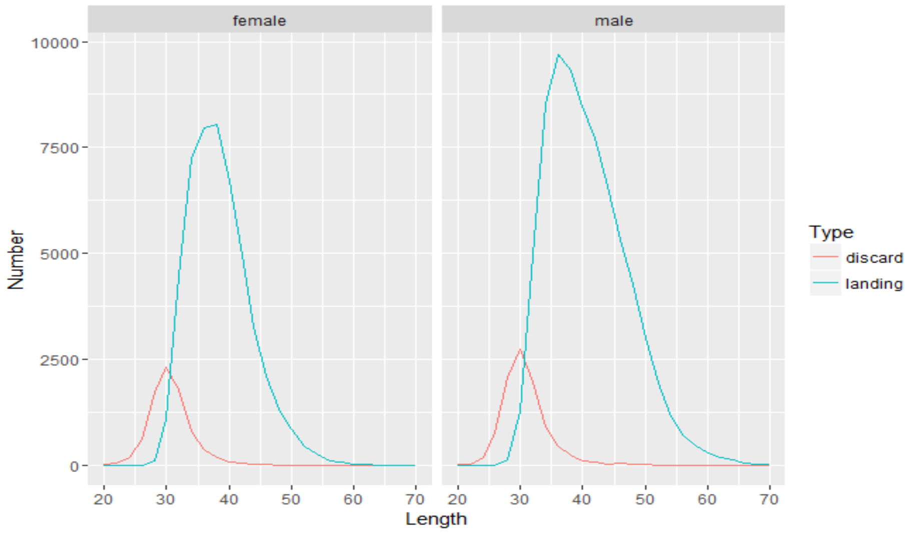


Figure 1. IIIa Nephrops. Landings and discard length frequencies by sex (average 2013-15)

LCA results (parameter estimates):

Discard survival	L50_c	K_c	Fq	L50_d	K_d
0 %	33.55	0.48	0.475	31.91	0.73
25 %	33.75	0.51	0.472	31.49	0.72
50 %	33.90	0.55	0.470	30.88	0.71

'Dead removals' selection ogive is parameterised by a logistic curve (parameters L50_c and K_c)

Fq is the relative catchability of mature female Nephrops

Discard ogive is reverse logistic (with L50_d and K_d)

Comparison of parameters:

Overall the estimated parameters from the 3 runs are very similar. With 0 discard survival, the selection curve is further to to the left (smaller individuals) as expected. The discard L50 is higher at 0 % survival – more discards at bigger sizes.

The dead removals length frequencies do not change a great deal for the two different assumptions about discard survival (see figure 2). (Mean length of both male and female removals only increases by approximately 0.5 mm with a change from 0 to 50 % discard survival)

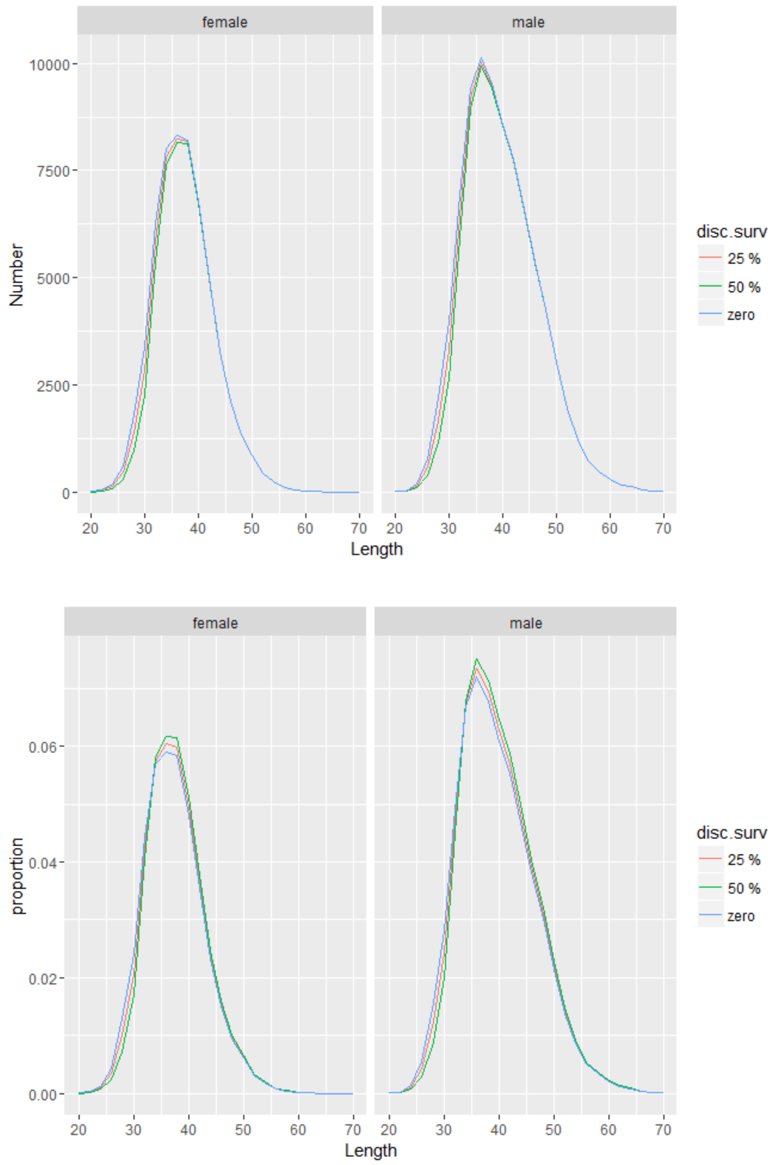


Figure 2. IIIa Nephrops. Comparison of catch (dead removals) length frequency distributions for different assumptions of discard survival (upper: totals, lower: proportion). Data averaged over 2013-15.

NB. As in previous analyses the LCA is a fairly poor fit (see figures below) – although little difference across the 3 scenarios – I think previously we fiddled around with the growth parameters to improve it (a lower female Linf would help I think).

Per recruit analysis

Not much difference between the three sets of per-recruit harvest rates at the reference points (unsurprising given the very small changes in the input parameter values).   However, compared to the previous reference points, the harvest rate at Fmax is much higher – due to the fact that the discard rate is now very low (previously it was very high). YPR is now maximised at a higher fishing mortality as a higher % of the removals are now landed rather than discarded.

0 % discard survival	Fmult	F(M)	F(F)	HR	SSB%(M)	SSB%(F)	SSB%(T)
F0.1(M)	0.25	0.09	0.06	6.49	41.42	54.98	49.21
F0.1(F)	0.39	0.15	0.09	8.97	30.76	43.92	38.32
F0.1(T)	0.3	0.11	0.07	7.44	36.86	50.42	44.65
Fmax(M)	0.52	0.20	0.12	10.85	24.87	37.15	31.92
Fmax(F)	0.84	0.32	0.19	14.40	17.11	27.30	22.97
Fmax(T)	0.66	0.25	0.15	12.56	20.69	31.99	27.18
F35%(M)	0.33	0.13	0.07	7.97	34.57	48.04	42.31
F35%(F)	0.58	0.22	0.13	11.62	22.87	34.73	29.68
F35%(T)	0.46	0.17	0.10	10.02	27.27	39.97	34.57

25 % discard survival	Fmult	F(M)	F(F)	HR	SSB%(M)	SSB%(F)	SSB%(T)
F0.1(M)	0.25	0.09	0.05	6.34	41.76	55.51	49.67
F0.1(F)	0.4	0.15	0.09	8.90	30.60	43.94	38.27
F0.1(T)	0.31	0.11	0.07	7.44	36.43	50.18	44.34
Fmax(M)	0.56	0.21	0.12	11.06	23.93	36.19	30.97
Fmax(F)	0.93	0.34	0.20	14.72	16.25	26.26	22.00
Fmax(T)	0.73	0.27	0.16	12.92	19.57	30.70	25.96
F35%(M)	0.33	0.12	0.07	7.78	34.95	48.64	42.82
F35%(F)	0.6	0.22	0.13	11.53	22.72	34.70	29.60
F35%(T)	0.47	0.17	0.10	9.90	27.24	40.13	34.65

50 % discard survival	Fmult	F(M)	F(F)	HR	SSB%(M)	SSB%(F)	SSB%(T)
F0.1(M)	0.26	0.09	0.05	6.41	41.05	55.03	49.09
F0.1(F)	0.42	0.15	0.09	8.98	29.89	43.36	37.63
F0.1(T)	0.32	0.12	0.07	7.45	35.98	49.93	44.00
Fmax(M)	0.61	0.22	0.13	11.34	22.81	34.99	29.81
Fmax(F)	1.07	0.39	0.22	15.29	15.03	24.68	20.58
Fmax(T)	0.82	0.30	0.17	13.37	18.31	29.19	24.56
F35%(M)	0.34	0.12	0.07	7.78	34.56	48.44	42.54
F35%(F)	0.61	0.22	0.13	11.34	22.81	34.99	29.81
F35%(T)	0.48	0.17	0.10	9.80	27.18	40.25	34.69

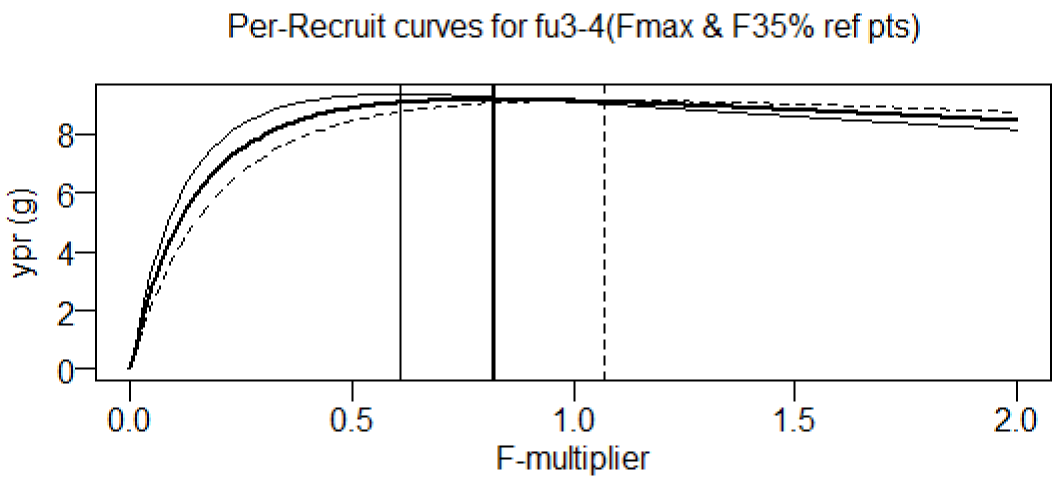


Figure 3. IIIa Nephrops. Per-recruit curves and reference points (shows Fmax M/F/T & F35% M/F/T) for run with 50 % discard survival. LCA input data averaged over 2013-15.

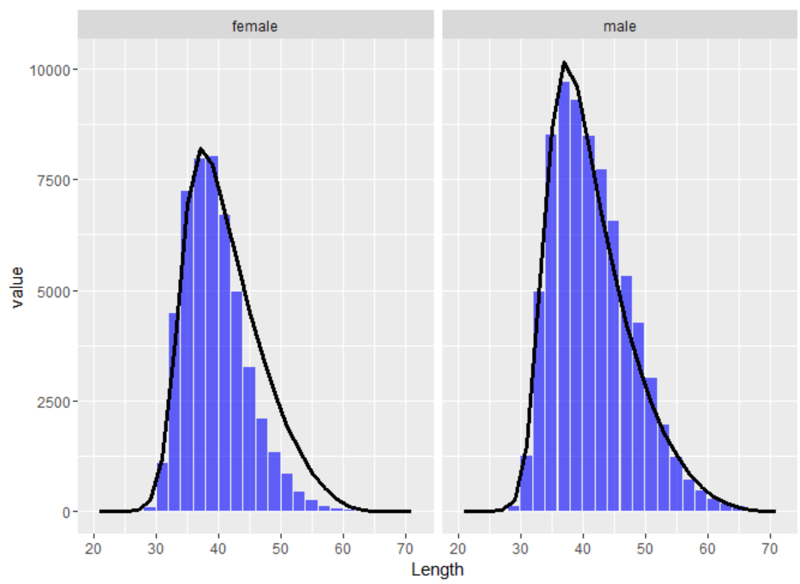


Figure 4. IIIa Nephrops. Observed and estimated landings length frequency distributions (50% disc survival).

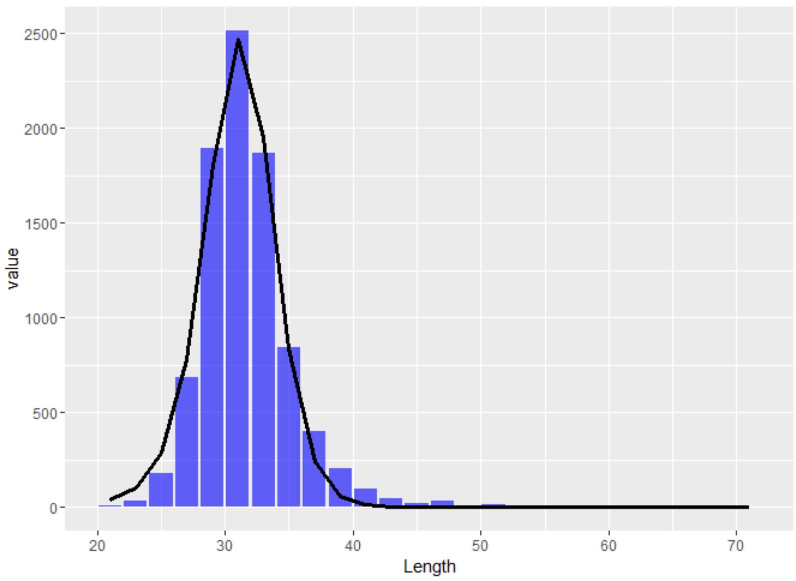


Figure 5. IIIa Nephrops. Observed and estimated discard length frequency distribution (50% disc survival).

A model to derive stock indices for *Nephrops* from a trawl survey

Carsten Hvingel, Guldborg Søvik and Ann Merete Hjelset

Introduction

There is no fishery independent stock size index for *Nephrops* in FU 32 (Norwegian Deep west of Lindesnes). A UWTV survey was implemented for *Nephrops* in FUs 3 and 4 (Skagerrak and Kattegat) in 2010, but this survey does not cover the Norwegian Skagerrak coast. The annual Norwegian shrimp survey, which commenced in 1984, covers the whole Skagerrak and Norwegian Deep. Catches of *Nephrops* in the Campelen trawl are small and highly variable. The 2013 benchmark of the FU 32 *Nephrops* still recommended closer investigation of these survey data in order to establish a fishery-independent stock size index.

A prevalent feature of the *Nephrops* data from the shrimp survey is hauls without catch. It is a common problem (e.g. Maunder and Punt 2004; Fletcher et al. 2005; Martin et al. 2005; Hvingel et al. 2012), and such data—highly skewed, and not drawn from a standard distribution—pose problems in analysis, in particular with respect to the calculation of confidence distributions, even for the estimate of a simple statistic such as total numbers or biomass. Several *ad hoc* methods have been practiced to deal with this problem but are not recommended (c.f. Hvingel et al. 2012).

Other methods providing a statistically more rigorous treatment of survey data including zeros have been developed (e.g. Maunder and Punt 2004; Fletcher et al. 2005; Martin et al. 2005; Shono 2008; Zuur et al. 2009; Hvingel et al. 2012). The basic 'Delta' method comprises the fitting of two separate models, one for occurrence (zeros and non-zeros) and a second for the distribution of densities at sites with non-zero catches. Stefánsson (1996) suggested using a multi-year GLM within the Delta approach, and this combination has the advantage that by analysing an entire series instead of just one year at a time, the spatial pattern of stock density can be modelled by including area variables. Other structuring—e.g. environmental or species behavioural—variables can also be added to account for components of the residual variation other than a year effect. Such a GLM structure can also accommodate missing data, typically originating from incomplete surveys.

Based on the work of Hvingel et al. (2012) we present a Bayesian version of a GLM within the Delta model and generate probability density distributions of the annual survey estimates in the units of the raw data.

Methods

Trawl data

A trawl survey for northern shrimp (*Pandalus borealis*) in Skagerrak (FU 3) and the Norwegian Deep (FU 32) has been conducted annually by the Norwegian Institute of Marine Research since 1984. The survey data consist of three different time series:

1. 1984-2002 (October/November) with R/V *Michael Sars* and a Campelen-trawl.
2. 2003 (October/November) with R/V *Håkon Mosby* and a Shrimp trawl 1420 (the winches of *Håkon Mosby* at that time were not powerful enough for the Campelen-trawl).
3. 2004-2005 (May/June) with R/V *Håkon Mosby* and the Campelen trawl.

4. 2006-2016 (January/February) with R/V *Håkon Mosby* and the Campelen trawl.
5. From 2017 onwards, the survey will be conducted with a new research vessel R/V *Kristine Bonnevie*, still in January/February using the Campelen trawl.

The survey is stratified into nine strata (Figure 1, Table 1) and has a fixed station design. Due to time and weather constraints, not all strata have been covered in all years.

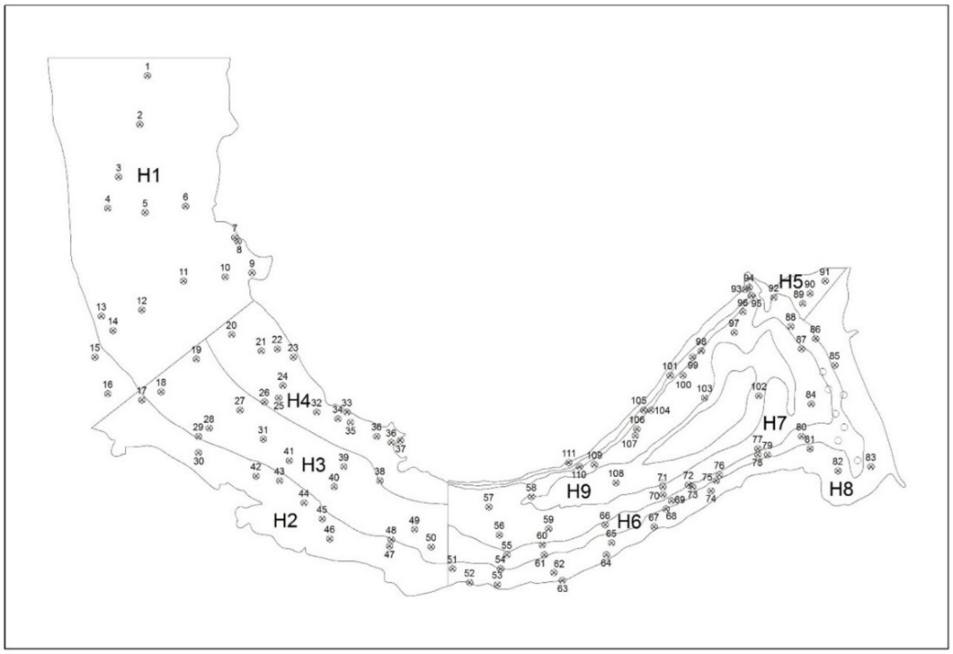


Figure 1. Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32): strata system, based on depth contours and area, with fixed trawl stations. Strata areas (nm^2) are given in Table 1.

Table 1. Strata of the Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32): strata names, depth intervals (m) and area (nm^2).

In map*	Strata name	Depth (m)	Area (nm^2)
H1	H_NDN_200	200-300	4037
H2	H_NDS_100-200W	100-200	1393
H3	H_NDS_200-300W	200-400	1705
H4	H_NDS_200-300E	200-400	1119
H5	H_SK_100-200N	100-200	365
H6	H_SK_200-300	200-300	988
H7	H_SK_300-500	300-500	1866
H8	H_SK_100-200S	100-200	1403
H9	H_SK_500-600	500-600	815

*map in Figure 1.

The survey trawl is a Campelen 1800/35 bottom trawl with rockhopper gear. Mesh size in the cod end is 20 mm with a 6 mm inner lining net used in most years. Tow duration was 1 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.

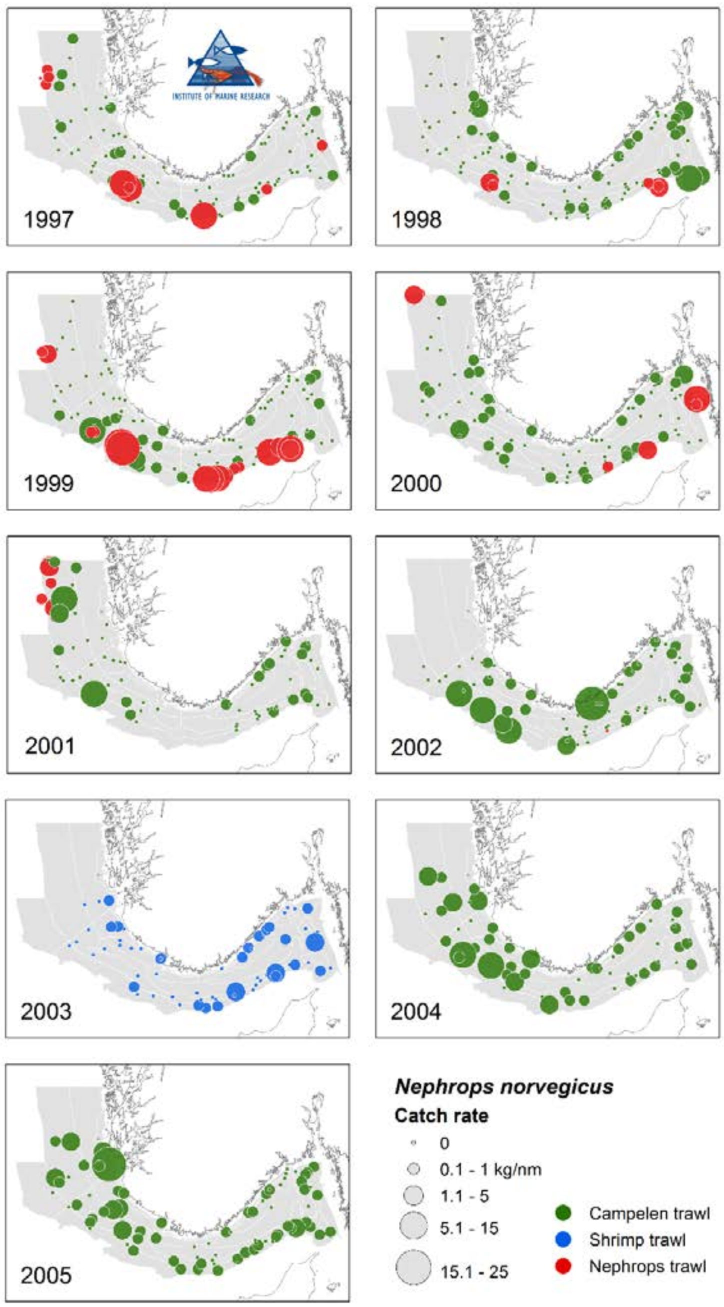


Figure 2a. Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32): Catches of *Nephrops* per trawl stations (kg/nm) per gear, 1997-2005.

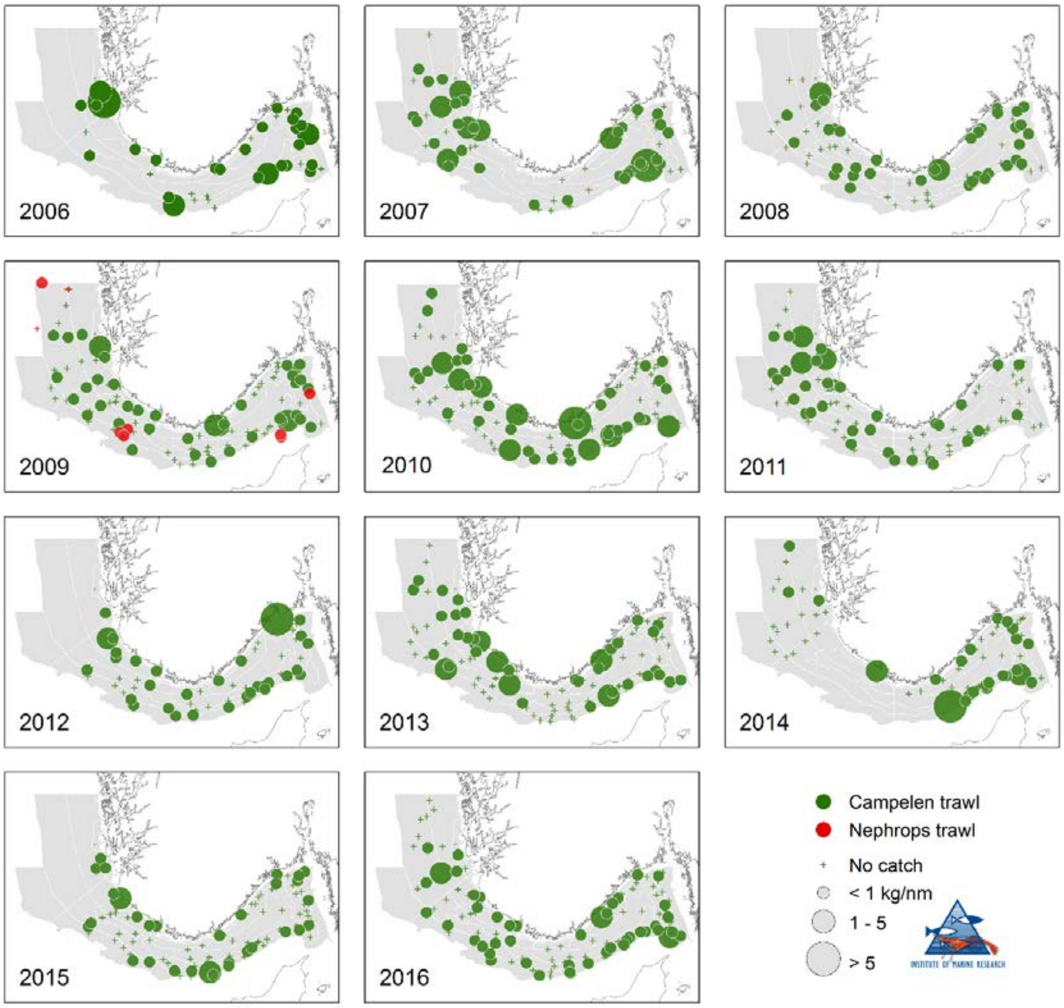


Figure 2b. Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32): Catches of *Nephrops* per trawl stations (kg/nm) per gear, 2006-2016.

Since 1997, *Nephrops* have been recorded on the shrimp survey (number, total weight, length, sex). Hauls with a special *Nephrops* trawl (70 mm cod end) were carried out until 2002, and again in 2009 (Figure 2ab).

Data from trawl stations where either the trawl did not operate as it should and/or the trawl was damaged, were omitted. All hauls with gear other than the Campelen trawl were excluded from the analysis. Furthermore, all non-regular trawl hauls (gear experiments, day stations, calibration of equipment) were excluded (Table 2). The number of valid stations vary from 43 to 105 (Table 2). For some trawl hauls in some years, catch weight of *Nephrops* was not recorded, only catch number. For these stations, catch weight was estimated as the catch number multiplied by the mean weight of *Nephrops* from that particular year, obtained as total weight divided by total number (from all trawl stations where both number AND weight was recorded) (Table 3). In this paper, we analyze the data from 2006 until 2016. The 2016-data should have been excluded from the analysis, as the survey this year is considered invalid due to problems with the winches and unequal wire length.

Table 2. Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32): Number of valid trawl stations per year, number of stations where weight has been estimated (see Table 3), and number of special stations (gear trials, calibration, day stations). The 2003-data are deleted from the analyses as the survey was carried out with a different gear this year.

Year	Valid stations	Stations with missing weight	Special stations
1997	93		
1998	95		
1999	97		
2000	98		
2001	70		
2002	77		
2003			
2004	60	1	
2005	84	1	6 out of 7 day stations deleted
2006	43		
2007	59		5 gear stations deleted
2008	73		
2009	91		
2010	95	10	
2011	89		9 out of 10 day stations deleted
2012	63		
2013	101		
2014	69		
2015	89		
2016	105		2 calibration stations deleted

Table 3. Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32): Trawl stations with missing catch weight: serial number, number of *Nephrops*, annual mean weight, and estimated catch weight.

year	serial number	catch number	mean_weight	estimated catch weight
2004	30430	5	45.67	228
2005	22154	10	54.72	547
2010	22012	1	59.04	59
2010	22015	1	59.04	59
2010	22016	1	59.04	59
2010	22017	2	59.04	118
2010	22025	5	59.04	295
2010	22026	8	59.04	472
2010	22031	6	59.04	354
2010	22032	11	59.04	649
2010	22060	5	59.04	295
2010	22062	1	59.04	59

Distribution of the data

The data are considerably skewed (skewness 9.81) and include more zeros than can be fitted by standard distributions (Figure 3). The many zeros reflect a typical patchy distribution of this species, but also the extent of its spatial distribution within the surveyed areas. Overall stock size is a conflation of the extent of its distribution (the fraction of non-zeros) and the average density at occupied sites (the non-zeros); we modelled these two processes separately.

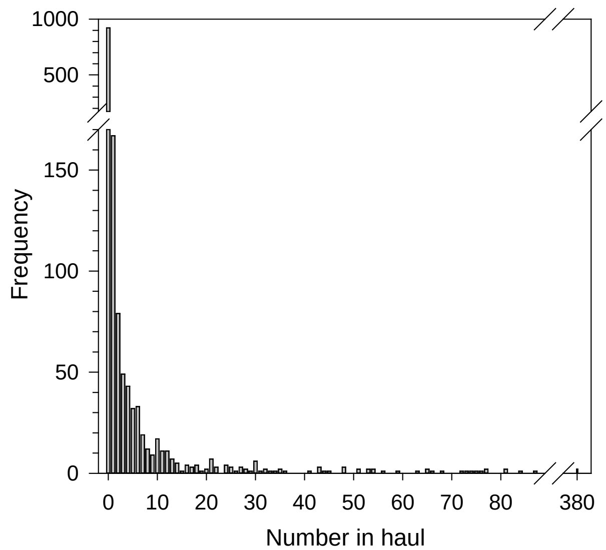


Figure 3. Norwegian shrimp survey in Skagerrak (FU 3) and the Norwegian Deep (FU 32): distribution of number of *Nephrops* in individual survey hauls.

The probabilities of zero catch were modelled by a Binomial distribution (see below). The non-zero part of the data is also positively skewed (skewness =5.18). The Gamma or Lognormal distributions are typically used to model such data (c.f. Stefanson 1996; Pennington 1996; Myers and Pepin 1990) and discussions on which of the two to use have been frequent (Syrjala 2000; Dick 2004). However, several other distributions might also be candidates. We tested different distributions using Goodness of fit statistics (Kolmogorov-Smirnov, Anderson-Darling, Chi-Squared) and visual inspections of probability plots across the data matrix to provide some guidance as to which to prefer.

Different approaches were now open, e.g.: 1. Run all models (each with its different assumptions about the distribution of the data) one by one and pick the “true” one judged by some relevant score of best fit statistics. 2. Run all models simultaneously and average across them in order to include all the different hypotheses of data distribution. Option 1 seemed a bit restrictive and would likely trap us in the old lognormal vs gamma discussion. While option 2 was closer to the ideal by including also model uncertainty, the problem of how to weigh the different models in the averaging process still needs to be resolved and the accompanied increase in model running time due to the increased complexity made this approach impractical. As a pragmatic solution we therefore decided to use the Generalised Gamma distribution as the model for the positive data. It has the great advantage of being a three-parameter distribution and therefore offering at least the possibility of being able to fit mean, variance and skewness with some measure of independence. The Generalised Gamma includes a number of standard non-negative positively skewed distributions as special cases (e.g. the Lognormal, Gamma, Exponential, Weibull etc.). Not among them are the loglogistic and inverse Gaussian distributions, which were therefore not investigated further although the initial analyses had identified them as possible candidates. We compared model results with those obtained by simply taking an arithmetic mean of all stations in each sampling unit – the standard "sum-of-strata-means" method.

The generalised gamma distribution

The generalised gamma distribution provides a general approach to the problem of fitting a distribution to skewed data. Its probability density function in the form commonly used (Stacy 1962; Stacy and Mihram 1965) is:

$$f(x) = \frac{\beta}{\Gamma(\kappa)\theta}\left(\frac{x}{\theta}\right)^{\kappa\beta-1} \exp\left(-\left(\frac{x}{\theta}\right)^{\beta}\right)$$

where ϑ (> 0) is a scale parameter, β (> 0) and κ (> 0) are shape parameters and $\Gamma(\kappa)$ is the gamma function of κ. Moments of the distribution are given by:

$$E\left(x^r\right) = \theta^r \frac{\Gamma\left(\kappa + \frac{r}{\beta}\right)}{\Gamma(\kappa)}$$

leading to

$$\theta \frac{\Gamma\left(\kappa + \frac{1}{\beta}\right)}{\Gamma(\kappa)}$$

for the mean of the distribution and

$$\sqrt{\frac{\Gamma\left(\kappa + \frac{2}{\beta}\right)\Gamma(\kappa)}{\left(\Gamma\left(\kappa + \frac{1}{\beta}\right)\right)^2} - 1}$$

for its CV.

In this form the distribution has a long-standing reputation for being difficult to fit: the parameters do not represent recognisable properties of the distribution, so it is difficult to provide starting values for fitting methods, and they are strongly related so that convergence can be difficult to achieve. Prentice (1974), working with the logarithm of the argument of the generalised gamma, mapped the lognormal limiting distribution, as k tends to ∞, to the origin ($l = 0$) using the transformation $\lambda = \frac{1}{\sqrt{\kappa}}$ and gave a limiting expression for the variance of the transformed variable (approximately the CV^2 of the parent) as $\sigma^2 = \frac{1}{\beta^2\kappa}$.

The logarithm of the mean is approximately

$$\mu = \ln(\theta) + \ln\left(\Gamma\left(\kappa + \frac{1}{\beta}\right)\right) - \ln\left(\Gamma(\kappa)\right)$$

which for β not small can be approximated by

$$\mu = \ln(\theta) + \frac{1}{\beta}\ln(k);$$

Prentice (loc. cit.) also demonstrated that the logged distribution, with the transformed parameters and extending the parameter space to include negative *l* so that the centre of the parameter space was occupied by a symmetrical normal distribution, was somewhat easier to fit by maximum likelihood (ML) methods than the standard form of the generalised gamma distribution.

<u>A main effects model for a survey-based stock size index</u>

The distribution of the biomass of individuals (y) in a haul may be approximated by a mixed probability function consisting of a binary discrete distribution for zero/non-zero and a continuous distribution, g(y), for the non-zero values:

$$f(y) = \begin{cases} 1-\pi & y = 0 \\ \pi \cdot g(y) & y > 0 \end{cases}$$

where π is the probability of a positive haul and $\int_{>0}^{\infty} g(y)dy = 1$. The expectation of y, i.e. $E(y)$, equal to $\pi \cdot \overline{g}$, i.e. the probability of getting a positive haul times the mean catch in the positive hauls, is the survey index of mean number for which an estimate is sought; using Bayesian methods for fitting the model made confidence intervals for these indices more accessible. Two separate General Linear Models (GLM) can then be constructed to predict, respectively, π and $g(y)$ and define the overall distribution of the data. In this example we use “area” (the strata definition, Figure 1) and time-of-day (two periods: “light” (0600 to 2000 hrs), “dark” (2000 to 0600 hrs)) (Figure 4) as explanatory variables taking spatial structure and *Nephrops* diurnal activity behaviour into account, and a time effect, year, as surveys are conducted on an annual basis.

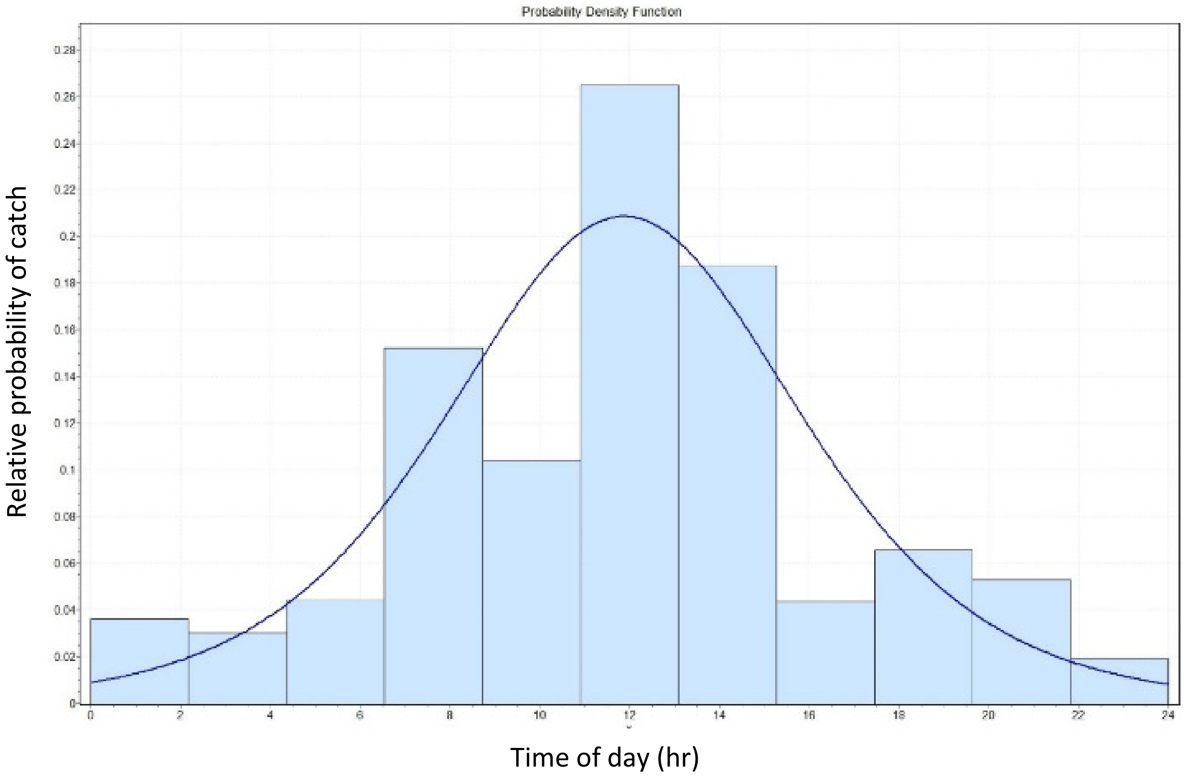


Figure 4. Probability of catching *Nephrops* during the day as inferred by the survey data.

<u>The GLM model for the occurrence of non-zero hauls</u>

Of n_{dat} hauls taken in day period d in area a in the year t, m_{dat} catch *Nephrops*. The variable m_{dat} is considered to have a binomial distribution with probability parameter π_{dat}:

$$m_{dat} \sim \text{Binomial}\left(n_{dat}, \pi_{dat}\right)$$

Using a logit link function to scale probabilities to effects, the probability π was described as having components:

$$\text{logit}\left(\pi_{dat}\right) = \alpha_{1,t} + \alpha_{2,\text{a}} + \alpha_{3,d}$$

where $\alpha_{1,t}$ was an effect of year t, $\alpha_{2,a}$ was an effect for area a and $\alpha_{3,d}$ was the effect of day period d.

<u>The GLM model for the abundance of *Nephrops* in non-zero hauls</u>

The density, y_{itad}, in the haul i taken at day period d in area a in the year t with positive catch was modelled by a generalised gamma distribution. This model was kept simple by assuming that the distribution of densities had the same shape in all sampling units, i.e. that the CV of density and its skewness were the same, regardless of the mean. In marine resource surveys, it is common to find that the CV of density is the same in sampling units of very different mean density–this was also the case for this survey (Figure 5).

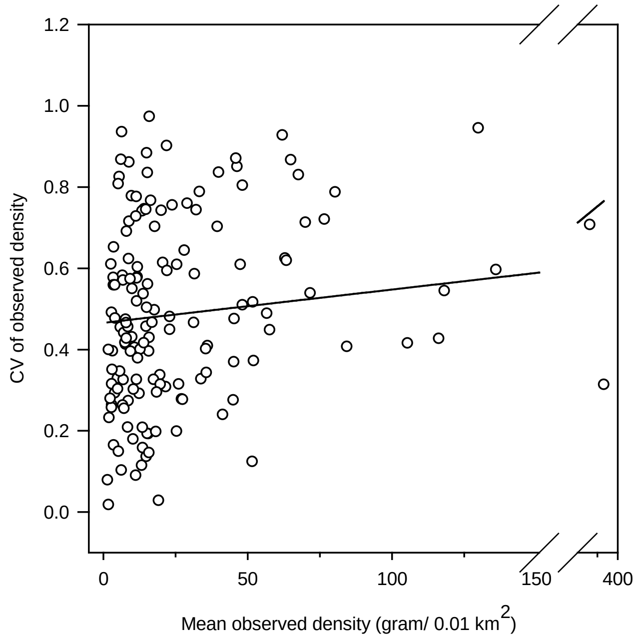


Figure 5. *Nephrops* in Skagerrak and Norwegian Deep: sampling-unit CV of density in non-empty hauls vs mean density; slightly positive but no statistically significant correlation.

This permitted fitting common values of kappa and beta, but different values for the mean density, to the year-area-depth combinations, so:

$$y_{itad} \sim gen.gamma(\kappa, \theta_{itad}, \beta)$$

Using a log link the predicted logarithm of mean density is:

$$\mu_{itad} = \gamma_{1,t} + \gamma_{2,\mathrm{a}} + \gamma_{3,d}$$

where $\gamma_{1,t}$ is an effect of year *t*, $\gamma_{2,a}$ is an effect of area *a* and $\gamma_{3,d}$ is the effect of day period *d*; as for presence-absence.

In applying Bayes's equation to the present problem, the posterior probability distribution of the survey indices was derived by Monte-Carlo-Markov-Chain (MCMC) sampling methods (see e.g. Congdon 2001). The programming framework OpenBUGS 3.2.3 provided a means of specifying and analysing a Bayesian model, including selection and implementation of appropriate algorithms (Spiegelhalter et al. 2004).

Lacking prior knowledge on the density or prevalence of the species, we used uninformative prior distributions for the model parameters. The year-area and depth effects, for both presence and density, were given uniform priors (in log space) between – 10 and 10, a range much wider than that of the observed densities. The (approximate) CV of the generalised gamma distribution, σ, was given a uniform prior between 0.5 and 4. The shape parameter, λ, was given a distribution uniform in log space between – 4 and the logarithm of the reciprocal of σ. This upper limit was chosen to ensure that the distribution of non-zero densities was not modelled as J-shaped, while the lower limit avoided computational difficulties that occurred in sampling from the generalised gamma distribution with large values of κ (which is the reciprocal of λ^2).

The generalised-gamma model was flexibly able to fit distributions ranging from lognormal to gamma. However, as we had to restrict the prior for *κ* to avoid computational difficulties with large values of *κ*, we also fitted a lognormal distribution as a check. It was defined by $\log(y_{itad}) \sim N(m_{tad}, s_{tad}^2)$ where the mean of the lognormal, $\exp(m_{tad} + s_{tad}^2 / 2) = \exp(\mu_{tad})$. The year, area and the depth effects, parameters in log space, were given prior distributions uniform from -10 to 10 (as when fitting the generalised gamma model version).

The year, area and day period effects were fitted without weighting the data, which implied assuming that the density of stations was nearly the same in all sampling units.

<u>The survey indices</u>
For each year-area combination the proportion of the area occupied by *Nephrops* was estimated by reversing the logit scaling:

$$P_{t,a} = \frac{\exp(\alpha_{1,t} + \alpha_{2,a})}{1 + \exp(\alpha_{1,t} + \alpha_{2,a})}$$

and the mean density of biomass in the occupied area was estimated by

$$M_{t,a} = \exp\left(\gamma_{1,a} + \gamma_{2,a}\right)$$

so the mean density of *Nephrops* biomass in the area *a* in year *t* was $P_{t,a} \cdot M_{t,a}$ and the total biomass in area *a* was $A_a \cdot P_{t,a} \cdot M_{t,a}$ where A_a was the extent of area *a*.

Results

Sex ratio and length frequencies

The number of animals caught in each year is low (Table 4, 5). However, visual inspection of the data (sex ratio and length frequencies) do not reveal any "outlier-years". Annual proportions of females in the catches vary between 0.1 and 0.4 in both the Norwegian Deep and Skagerrak (Figure 6). Length frequencies show that most *Nephrops* in the survey catches are between 25 and 64 mm CL, with some smaller and some larger animals caught in some years. There are no suspicious gaps in the length distributions in any year (Figure 7), indicating that the catchability of the trawl is similar from year to year.

Table 4. Total number of males and females, and proportion of females per year (2006-2015), from the Norwegian shrimp survey in the Norwegian Deep (FU 32). The survey was considered invalid in 2016 due to problems with the winches and unequal length of wire.

	males	females	% females
2006	166	111	0.40
2007	291	154	0.35
2008	54	15	0.22

2009	76	18	0.19
2010	105	47	0.31
2011	167	72	0.30
2012	47	33	0.41
2013	86	46	0.35
2014	7	1	0.13
2015	57	40	0.41
2016	survey thrown out		

Table 5. Total number of males and females, and proportion of females per year (2006-2015), from the Norwegian shrimp survey in the Skagerrak (FU 3). The survey was considered invalid in 2016 due to problems with the winches and unequal length of wire.

	males	females	% females
2006	158	82	0.34
2007	161	112	0.41
2008	62	9	0.13
2009	138	57	0.29
2010	177	114	0.39
2011	24	6	0.20
2012	95	52	0.35
2013	72	18	0.20
2014	87	76	0.47
2015	88	27	0.23
2016	survey thrown out		

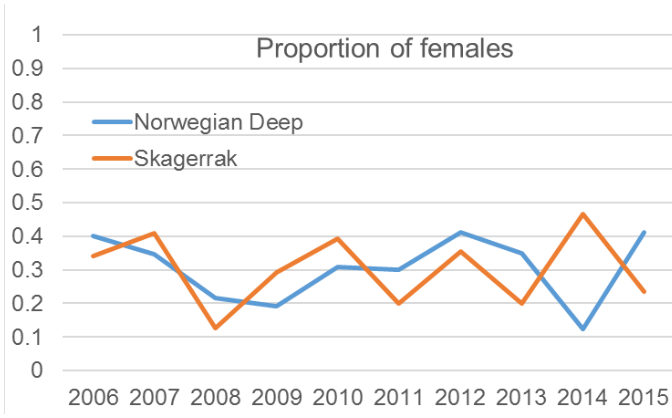


Figure 6. Proportion of females in survey catches per year (2006-2015) in the Norwegian Deep and Skagerrak. The survey was considered invalid in 2016 due to problems with the winches and unequal length of wire.

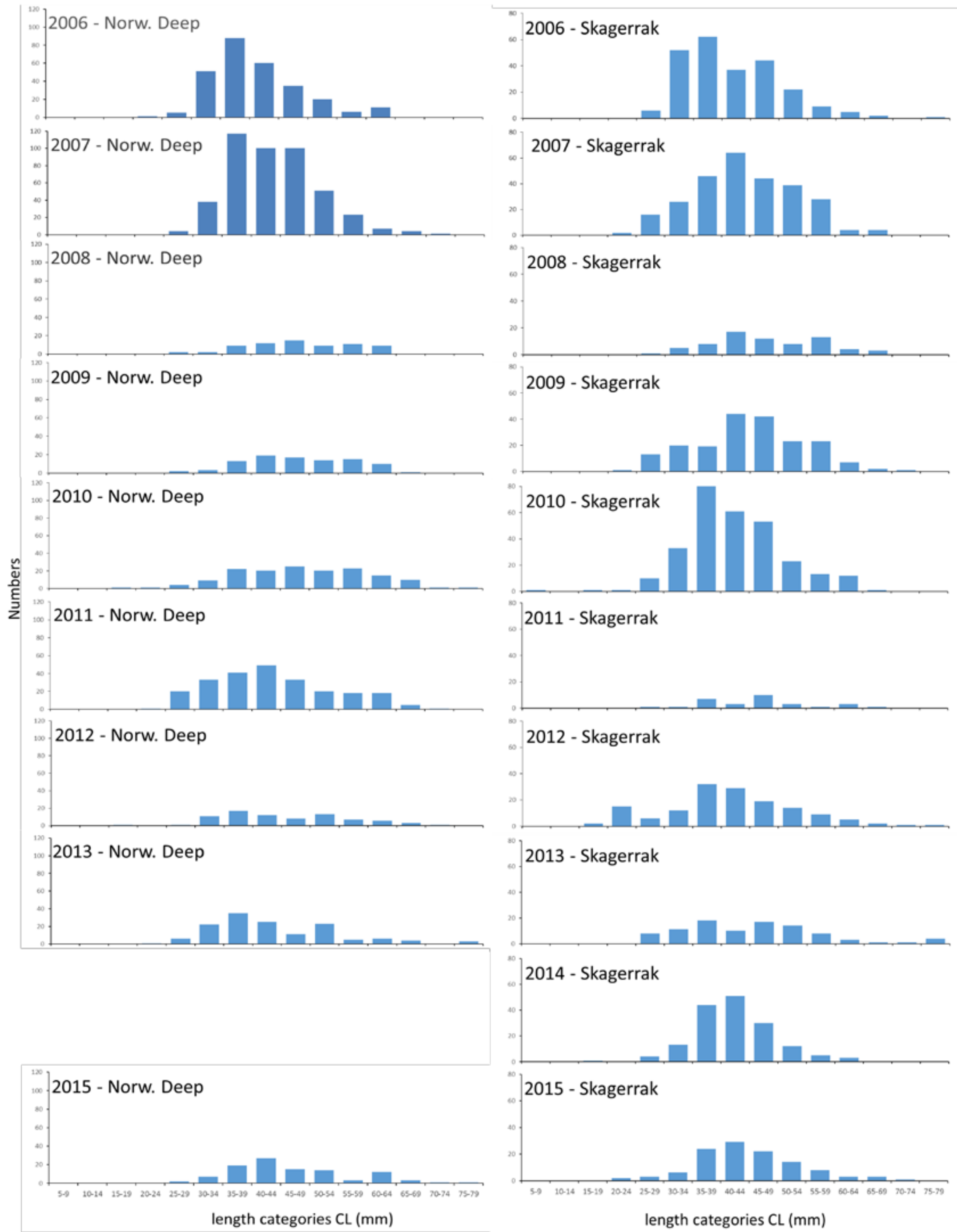


Figure 7. Annual length frequency distributions (2006-2015) in survey catches of *Nephrops* from the Norwegian Deep and Skagerrak. The plot from the Norwegian Deep in 2014 was not included due to few animals. The survey was considered invalid in 2016 due to problems with the winches and unequal length of wire.

Model fit and diagnostics

The generalised-gamma-binomial model converged orderly, and fitted well. All priors are strongly updated (Figure 8) and generally not constrained by limits on prior distributions; the exception was the limit of – 4 on the distribution of log(λ) in fitting the generalised gamma, which obviously also bounded the posterior distribution (Figure 8). We inferred that the data from the non-empty hauls probably were even more skewed than could be exactly fitted by the generalised gamma distribution with this limit on λ.

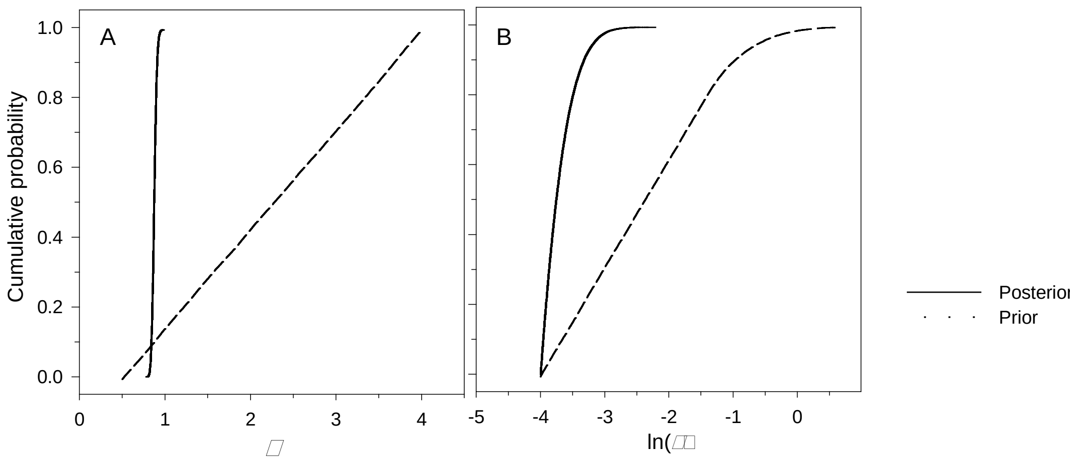


Figure 8. Norwegian lobster in Skagerrak and Norwegian Deep: prior and posterior cumulative probability density distributions of the parameters σ and λ of the generalised gamma model (A and B).

The presence-absence model fitted well to the observations, however, one outlier with a high residual was observed (Figure 9). This originated from stratum H9 which in general has poor coverage and low or no recordings of *Nephrops* (average estimated probability of a positive catch since 2006 is < 1.5%). But in the year 2009 1 specimen was caught in a total of two hauls and created the outlier.

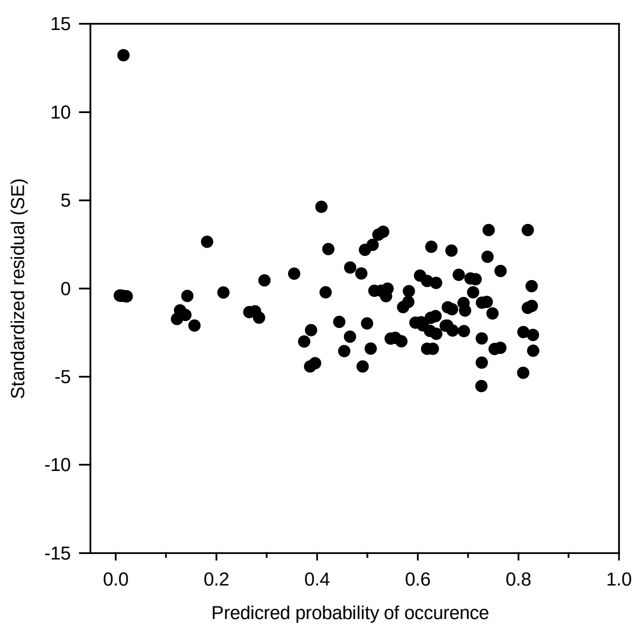


Figure 9. *Nephrops* in the Skagerrak and Norwegian Deep: Divergence between observed and median predicted (modelled) probabilities of non-empty hauls.

The proportion of occupied sites (non-empty hauls) are very low in stratum H9 (Figure 10A) and is estimated with high uncertainty. In stratum 7, you only find *Nephrops* in every fifth haul while 50-75% of the hauls in the remaining areas contain *Nephrops*. The nine areas follow a consistent slightly declining pattern over time (Figure 10B).

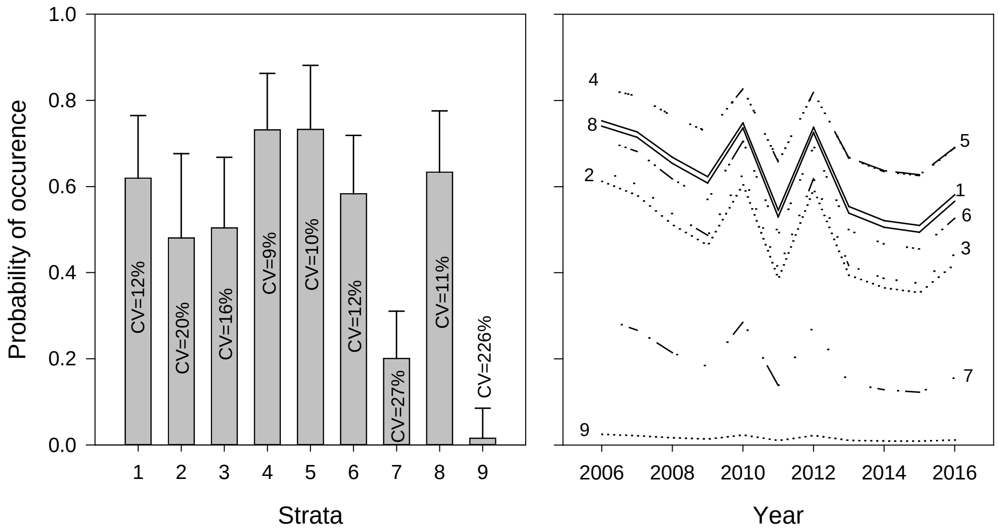


Figure 10. Mean probability of getting *Nephrops* in a haul in strata 1 to 9 during 2006 to 2016 (errorbars are 2 x average standard deviations; CV is average coefficient of variation). Panel A: averaged over 2006-2016; panel B: time trend.

The more complex model for density in occupied areas fitted common values for the two shape parameters to all the sampling units, the scale parameter being fitted with three sets of main effects. An ordered cumulation of probabilities that observed station densities would exceed the corresponding fitted values indicated a good fit over the entire range of values (Figure 11).

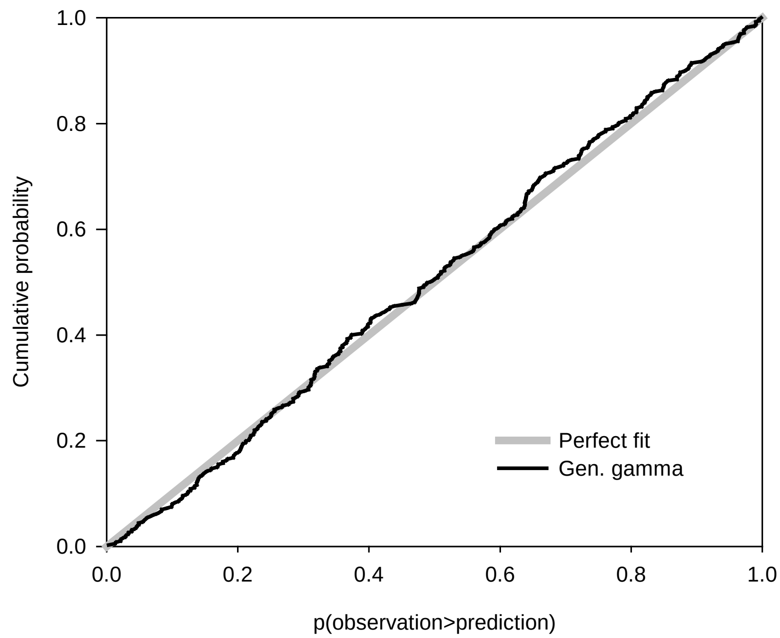


Figure 11. Cumulative probability density distributions of probabilities that observed densities in non-empty hauls exceed corresponding values predicted by the generalised gamma model.

A closer inspection of the residual (Figure 12) did, however, reveal some sampling units with very high positive residuals. These stem from sampling units including a single large haul, which would produce a high observed mean density for that unit. In these cases where there at the same time are few hauls in the sampling unit (<3) to draw information from, the model would tend to attribute that large haul to a random sample from a long tailed generalised gamma distribution with a much lower mean value. When sampling size increases the large residuals disappear.

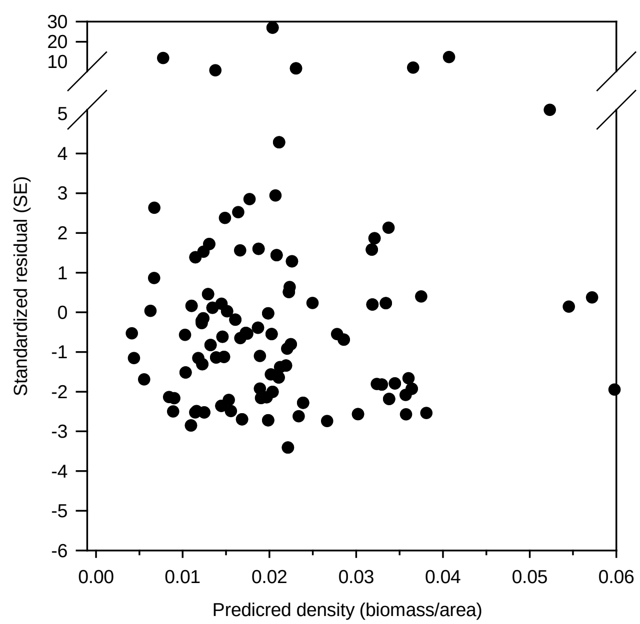


Figure 12. *Nephrops* in the Skagerrak and Norwegian Deep: Divergence between observed and median predicted (modelled) biomass density in the year-area combinations.

The density of *Nephrops* biomass are very low in stratum H9 (Figure 13A) and is estimated with high uncertainty. Strata 4 and 5 would be the ones producing the highest catch rates. Densities have been stable close to the average of the time series since 2012 (Figure 13B).

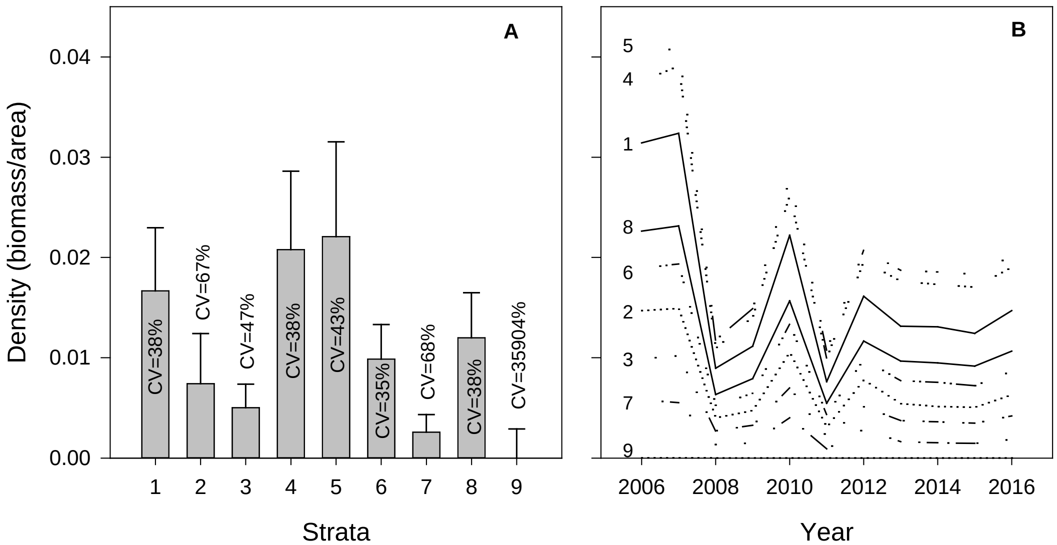


Figure 13. Mean density of biomass in strata 1 to 9 during 2006 to 2016 (error bars are 2 x average standard deviations; CV is average coefficient of variation). Panel A: averaged over 2006-2016; panel B: time trend.

The overall index of *Nephrops* biomass (Figure 14) had two relative high points in 2006 and 2007 and after that has varied at a lower level.

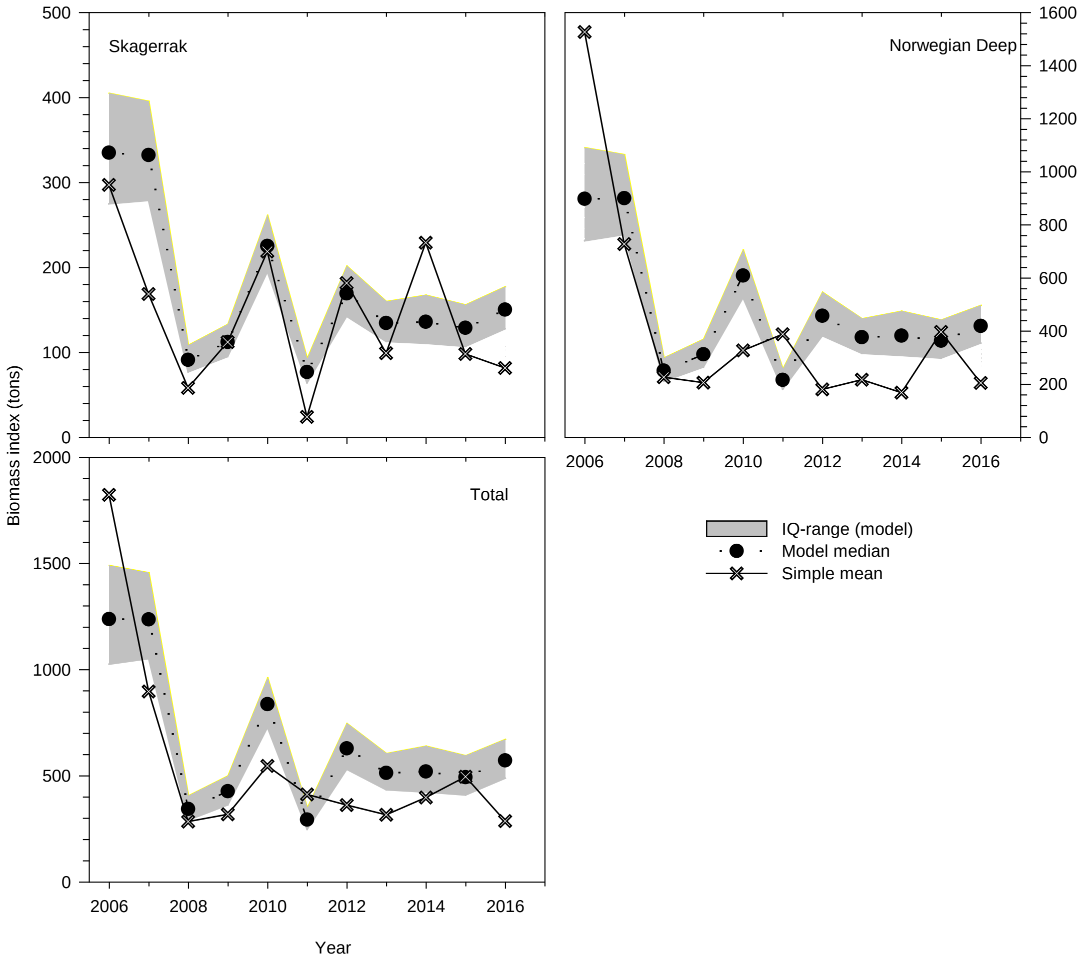


Figure 14. Estimated total biomass of *Nephrops* in the Skagerrak (FU 3) and Norwegian Deep (FU 32) and in the total area, 2006–2016, from the generalised gamma model and calculated from simple means in sampling units (crosses). The greyed area shows the inter-quartile range as estimated from the model. The dots indicate medians of the estimate of the means.

Table 6. Survey estimates of biomass (tons/km2). sd is standard deviation, pc is percentile.

	year	mean	sd	2.5pc	5.0pc	10.0pc	25.0pc	median	75.0pc	90.0pc	95.0pc	97.5pc
Norwegian	2006	936.5	276	509.8	557.9	620.1	740.4	898.4	1091	1296	1442	1578
Deep	2007	930.5	233.6	559.3	602.3	659.2	764.1	900.8	1065	1238	1358	1473
	2008	260	67.95	152.6	165	181.3	211.6	251.1	299.4	350.3	384.1	416.6
	2009	322.6	81.74	190.6	207.9	228.5	264.8	312.6	369.3	430.7	471.7	511.2
	2010	624.4	137.7	399.5	426.8	461.9	526	609.4	705.5	807.6	875.2	939.7
	2011	223.9	59.82	130.1	141.7	155.3	181.2	216	257.4	302.6	333.2	363.3
	2012	474.5	127.6	276.1	299.1	327.6	383.1	457.9	546.7	643.2	707.5	771.4
	2013	389.4	101.5	227.4	246.9	272.4	316.5	377.2	447	523.4	573.2	622.3
	2014	402.8	132.7	203.9	226.1	254.2	308.3	383	475.1	577.5	648.9	716.2
	2015	379	112.3	206.7	226.7	251	298.7	363.6	441.9	528	585.4	642.4
	2016	433.6	108.2	262.2	281.7	307.9	355.7	419.6	497.4	576.4	630.9	678.2
Skagerak	2006	349.2	106.1	191.5	208	231.7	275	335	405	482.3	537.1	592.9
	2007	344.8	96.22	201.8	216.7	238.8	278.9	332.3	395.6	465.4	512.1	559.9
	2008	94.51	24.84	55.93	60.55	66.27	77.08	91.23	108.4	126.7	139.2	151.3
	2009	116.3	30.25	69.18	74.87	81.9	95.23	112.3	133.1	155.4	170.7	185.1
	2010	232.1	55.46	147.9	158.6	171.1	194.9	225.3	261.3	300.2	327.3	353.4
	2011	80.18	23.01	45.28	49.2	54.41	64.15	76.92	92.58	109.7	122.1	133.6
	2012	175.8	49.25	102.8	111.2	122	142.5	169.4	201.7	235.7	261.7	284.3
	2013	139.2	37.48	80.95	87.73	96.56	113	134.5	160	186.8	206.6	224.2
	2014	142.7	45.3	74.46	81.86	91.75	110.8	135.9	167.3	201.9	225.5	250
	2015	134.3	38.44	75.02	82.15	91	107.2	128.9	155.9	183.9	202.9	222.2
	2016	155.3	39.56	93.42	100.6	110	127.8	150.3	177.4	206.3	226.1	244.6
Total	2006	1286	366.9	714.8	781.8	863.7	1026	1238	1491	1763	1957	2139
	2007	1275	312.4	776.4	836.6	911.3	1052	1236	1457	1684	1843	1999
	2008	354.5	88.46	212.9	230	251.2	291.7	343.4	405.7	472	515.5	556.4
	2009	439	106.4	266.6	288.1	315.6	363.5	427	499.7	579.4	632.8	683.8
	2010	856.5	179.9	559.9	598.7	644.6	728	837.3	961.5	1093	1183	1266
	2011	304.1	79.01	179.7	195.3	213.6	247.5	293.8	348.5	407.9	447.9	487.5
	2012	650.4	167.8	386.6	418.3	456.9	530.9	628.7	746.5	870.5	955.7	1038
	2013	528.5	132.1	316.4	342	375.2	434.5	513.5	604.5	702.2	770.1	830.8
	2014	545.5	172.4	283.6	314.8	350.8	423.2	520	639.8	770.8	862.5	950.5
	2015	513.2	144.6	288	315.1	347.2	409.9	493.3	594.6	704.8	777.9	846.7
	2016	588.9	139.8	363.1	392.2	425.1	489	571.9	671.4	775	841.3	905.3

Model fit and diagnostics - Separate indices for the Norwegian Deep and Skagerrak

Specialists considered that the survey data from FU 3 and FU 32 were likely to be systematically different, in particular because the survey in the Skagerrak would only cover the deeper range of the distribution of *Nephrops*. Estimates of *Nephrops* biomass indices were therefore calculated separately for the two areas using similar methods as described above.

The recalculated Skagerrak series seemingly show more year-to-year variability than the Norwegian Deep series (Figure 15) which might indicate an influence from annual variability in the survey coverage of stock distribution. The low value in 2011 is likely due to the cold bottom water in Skagerrak this year (mean of 5.4 ˚C vs. means of 7.0-7.5 ˚C in all other years back to 2006). The Norwegian Deep series is more “stable” except for a large decline in the beginning of the time series. There is a high uncertainty associated with the high 2006 estimate for this series.

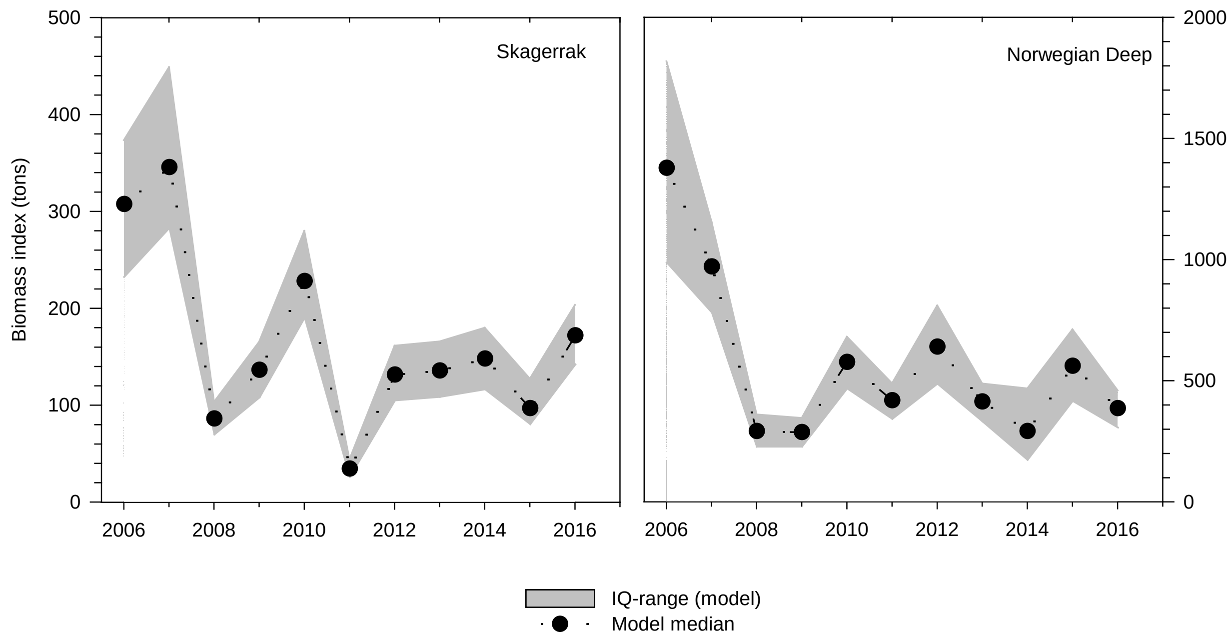


Figure 15. Estimated total biomass indices of *Nephrops* in the Skagerrak (FU 3) (survey strata 5 to 9) and Norwegian Deep (FU 32) (survey strata 1 to 4) calculated from separate models. The greyed area shows the inter-quartile range as estimated from the model. The dots indicate medians of the estimate of the means.

Table 7. Summary statistics of the estimated probability density functions of mean annual biomass of *Nephrops* in Skagerrak (upper) and Norwegian Deep (lower).

year	2.5pc	5.0pc	10.0pc	25.0pc	median	75.0pc	90.0pc	95.0pc	97.5pc
2006	491	567	690	935	1306	1819	2471	2965	3496
2007	491	543	608	741	920	1149	1416	1604	1780
2008	131	149	170	215	277	360	465	530	600
2009	136	153	172	214	272	348	434	494	554
2010	300	331	368	445	548	681	820	922	1016
2011	217	238	269	324	396	490	592	665	745
2012	268	310	361	462	609	810	1050	1214	1412
2013	208	229	259	315	393	490	605	691	773
2014	61	77	103	165	277	470	749	993	1272
2015	216	254	296	394	532	713	931	1105	1261
2016	189	210	238	291	366	462	574	653	731
2006	153	168	191	232	290	369	452	511	568
2007	169	187	210	261	334	423	518	601	663
2008	46	51	57	68	84	103	125	139	152
2009	71	79	88	106	132	162	198	221	243
2010	136	148	162	188	226	272	323	361	391
2011	13	15	18	24	32	43	56	66	77
2012	70	78	88	105	130	161	196	222	242
2013	66	73	83	104	131	164	204	235	263
2014	76	85	94	116	146	181	219	249	282
2015	52	57	64	78	96	121	149	168	187
2016	93	101	111	134	165	202	244	272	305

Regarding the question raised in plenary about the choice of assumed distribution for the positive data: The method used is very flexible as many standard distributions are special cases of the generalised gamma distribution (Lognormal, Weibull, Exponential, Gamma, Fréchet) as well as an infinite number of intermediates of that subset. In my experience the choice of long-right-hand-tailed-distribution for data such as the *Nephrops* data doesn't matter that much for the central part of the estimated probability density distribution—where it matters is for the estimation of the length of the right-hand tail. There will only be few data points to help us to make a good estimate of this "tail" and therefore the choice of distribution will dominate its shape rather than the data.

Part of the fuzz about the importance of the choice of distribution I think stem from the use of the mean as a summary statistic of the probability distribution. The mean will indeed be more sensitive to the length of the "tail"—probability distributions that look quite similar can have quite different means due to the length of the tail. If a point summary statistic is to be used, the median is a more stable one and even more so the mode.

Acknowledgements

We would like to thank the people conducting the surveys: crew, technicians and scientists.

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Coexistence *Nephrops/Munida*. Explorations from the UWTV survey data on the FU23-24 *Nephrops* stock.

Spyros FIFAS & Michèle SALAUN

Correction factors for the edge effect and for the detection rate have been accurately estimated for the Bay of Biscay *Nephrops* on the years' 2014-2016 UWTV surveys. The present WD involves in the coexistence between Norway lobsters (*Nephrops norvegicus*) and squat lobsters (*Munida sp.*) and a certain capacity of the second species to colonise *Nephrops* burrows affecting by this way the correction factor of the "species identification".

The interaction *Nephrops* and *Munida* is not relevant for other *Nephrops* stocks already routinely video surveyed either because of the depth (Iberic stocks, bank of Porcupine) or due to the latitude as *Munida* is more southerly spread than *Nephrops* in the NW Atlantic waters.

1 Information from footage (2014-2016)

The video tracks on 24h/24 of continuous observation provide valuable information on the dial activities and behaviour of the species.

Available data on the number of individuals for both species by track and per minute are aggregated by 30 min interval[1].

The data are processed by the following way:

(1) Time t is expressed by the difference between the time of a video track and the sunrise or sunset by matching each station with the chronologically nearest event: *e.g.* if a video track is undertaken at 10.45 am and the sun rises at 7.00 am whereas it sets at 7.00 pm, the station is joined to the sunrise and t=3.75.

(2) In order to standardise the expression of time t *vs.* the assumed standard light conditions (*i.e.* for a given day, 2 h after the sunrise are equivalent to 2 h before the sunset) opposite signs were attributed to the differences calculated as above: *e.g.* for a given day, with sunrise and sunset respectively occurring at 7.00 am and 7.00 pm, a station sampled at 10.45 am, closer to the sunrise and another one sampled at 3.15 pm closer to the sunset have the same value t (t=3.75).

[1] The ½ hour interval was chosen to calibrate UWTV observations with trawl indices by ½ hour haul operations carried out in 2014 and 2015 (stopped in 2016).

(3) The positive values for time t correspond to the interval between sunrise and sunset whereas the negative values involve in night.

(4) The abundance indices per surface unit are standardised in order to calculate by species a relative index for the whole day equal to 1 accordingly to a multiplicative approach (*i.e.* the product of the indices given in the figures below is equal to 1). Those indices are provided for the active individuals during the video track. For *Nephrops*, two values are available in the UWTV database: individuals in activity outside the burrows but also ones discernible in the burrow entries. For the *Nephrops* abundance index, both numbers of individuals are accumulated assuming that an animal discernible in a burrow either it gets ready to go outside or it has just entered otherwise it could not be seen as the complexity of burrow structures would not allow to observe it.

After these precisions for the data processing, results for both species are provided for year 2014 (fig. 1 and 2; tables 1 and 2).

Nephrops

Fitting of the *Nephrops* dial rhythm model is performed by the equation below using a Gauss curve:

$$\boxed{y = C1 + \frac{C2}{\sigma\sqrt{2\pi}}.\exp[-1/2*((t-\mu)/\sigma)^2]}$$

with: y= relative index of the abundance by surface unit (100 m² of track) accordingly to the number of individuals observed by video; t= standardised time of observation *vs.* sunrise or sunset (see above); C1, C2, σ, μ= model parameters.

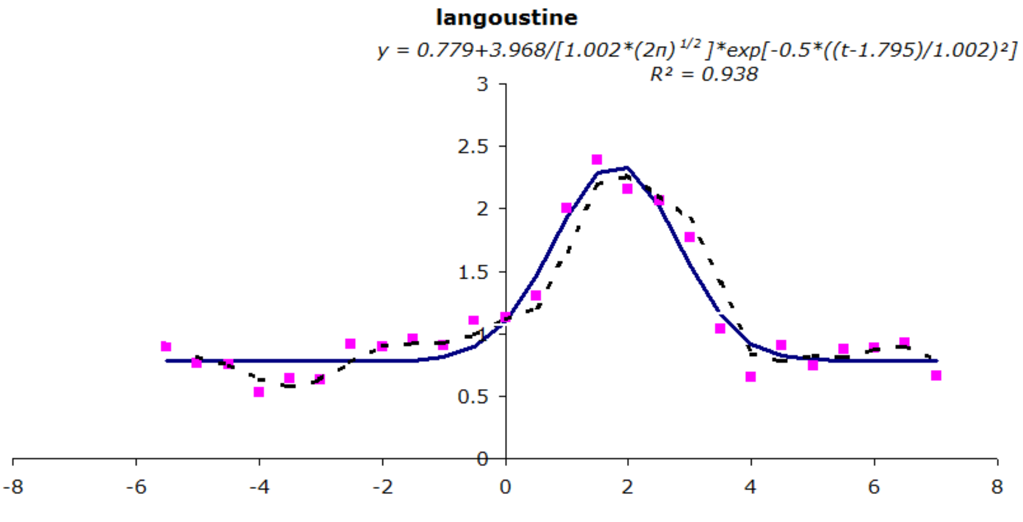


Figure 1. Relationship between standardised time of observation *vs.* sunrise/sunset and *Nephrops* activity. Abundance index per surface unit of video track. Data 2014 *(broken curve: data smoothed by mobile average).*

Table 1. Fitting of the abundance relative index for *Nephrops* (track surface of 100 m^2, multiplicative approach) *vs.* time of day for video observation (standardised accordingly to sunrise or sunset as explained above). Data 2014.

				matrix of correlations		
Parameter	Value	S.D.	CV	C2	M	σ
C1	.7788	.0379	.0487	-.6401	.0000	-.4334
C2	3.9683	.3157	.0796		.0000	.6780
μ	1.7952	.0706	.0393			.0000
Σ	1.0016	.0785	.0784			

number of observations (day divided into 30 min intervals): n=26
(156 UWTV stations)
SCE= .5072
coefficient of determination: R^2= .9381

Munida

Fitting for squat lobster is performed using and equation of 2nd degree:

$$y = C + \alpha 1 * t + \alpha 2 * t^2$$

with: y and t defined as previously and C, α1, α2= model parameters.

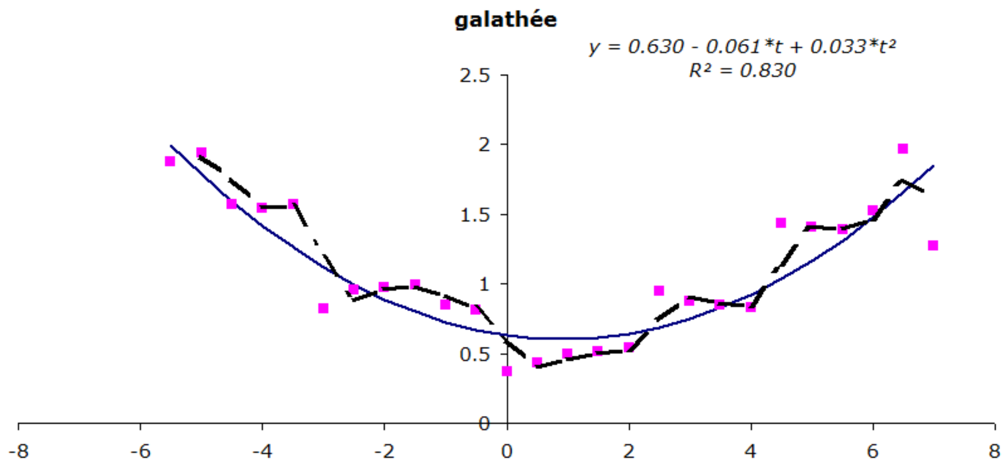


Figure 2. Relationship between standardised time of observation *vs.* sunrise/sunset and *Munida* activity. Abundance index per surface unit of video track.. Data 2014 *(broken curve: data smoothed by mobile average).*

Table 2. Fitting of the abundance relative index for *Munida* (track surface of 100 m², multiplicative approach) *vs.* time of day for video observation (standardised accordingly to sunrise or sunset as explained above). Data 2014.

				matrix of correlations	
Parameter	Value	S.D.	CV	α1	α2
C	.6301	.0552	.0877	.1737	-.7257
α1	-.0618	.0109	.1763		-.4090
α2	.0338	.0030	.0879		
number of observations (day divided into 30 min intervals): n=26 (156 UWTV stations)					
SCE= 1.1974					
coefficient of determination: R^2= .8303					

Modelling dial activities for both species on the basis of UWTV data 2014 shows that *Nephrops* and *Munida* have opposite patterns. In connection with field observations and with the fishermen experience, *Nephrops* has an activity pattern increasing around dawn and dusk. Results presented in this WD underline that the species activity is maximised at almost 2 h after sunrise (and symmetrically 2 h before sunset): the model deriving from a Gauss density of probability highlights that the relative abundance index on the track is maximum for μ=1.795.

Munida has a wider than *Nephrops* range of dial activity during the overall day with a minimum level around sunrise and sunset. According to the models' parameters, the *Nephrops* relative abundance index at sunrise and sunset reaches a value of 1.096 (+9.6% of activity compared to the averaged daily level) whereas for *Munida* the index is equal to .630 (it drops up to –37% compared to the averaged daily level). Moreover, *Nephrops* activity is maximised at t=1.795: its value is equal to 2.359 (+136% compared to the overall day averaged level).

It should be appropriate to examine the dial periodicity on other *Nephrops* stocks studied by UWTV. Nevertheless, this comparison should not be valid for *Munida* as this species seems to be more southerly spread, thus of minor contribution among the burrowing crustaceans on the routinely surveyed by UWTV sea bottom (ICES areas VI and VII).

The same type of model was also fitted on the *Nephrops* UWTV data for years 2015 and 2016 (fig. 3; table 3).

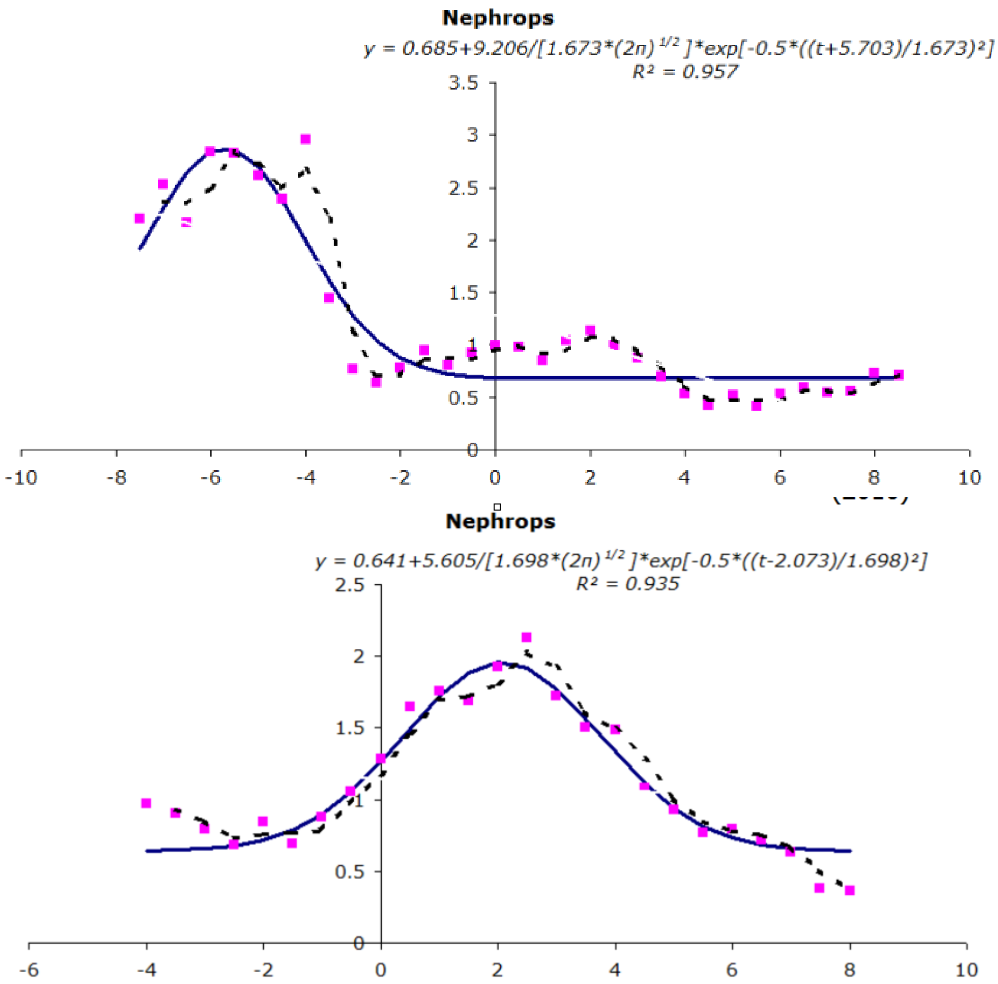


Figure 3. Relationship between standardised time of observation *vs.* sunrise/sunset and *Nephrops* activity. Abundance index per surface unit of video track. Data 2015 (above) and 2016 (below) *(broken curves: data smoothed by mobile average)*.

Table 3. Fitting of the abundance relative index of *Nephrops* (track surface of 100 m^2, multiplicative approach) *vs.* time of day for video observation (standardised accordingly to sunrise or sunset as explained above). Data 2015 and 2016.

			2015			
				matrix of correlations		
Parameter	Value	S.D.	CV	C2	M	σ
C1	.6847	.0676	.0988	-.5075	-.0166	-.3335
C2	9.2056	1.6052	.1744		-.3167	.9179
μ	-5.7035	.1622	.0284			-.3435
σ	1.6733	.3225	.1927			

number of observations (day divided into 30 min intervals): n=33
(96 UWTV stations)
SCE= 2.7680

coefficient of determination: R^2= .9569

2016						
				matrix of correlations		
Parameter	Value	S.D.	CV	C2	μ	σ
C1	.6413	.0578	.0901	-.8245	.0003	-.6768
C2	5.6048	.9241	.1649		-.0002	.9168
μ	2.0727	.1139	.0549			-.0002
Σ	1.6982	.2627	.1547			

number of observations (day divided into 30 min intervals): n=25
(196 UWTV stations)
SCE= .5162
coefficient of determination: R^2= .9347

The additional data 2015 and 2016 reveals the robustness of the model which provides low CV of the parameters. The 2016's survey (early May) seems to be very close to the 2014's one (late September) as the maximum activity for *Nephrops* occurs around 2 h after sunrise or before sunset. However, the fitting of the 2015's model (UWTV in late July) shows a shift of the pattern: the maximum activity for the species is observed 5-6 h after sunrise or before sunset (at the end of July in the Bay of Biscay this is equivalent to range around 11 pm-1 am).

UWTV survey season has differed from year to year because of constraints due to the equipment (vessel, sledge) made available by the “Marine Institute”. Trawling associated to the UWTV operations in 2014 and 2015 was considered not necessary and was abandoned in 2016. Therefore, season change does not affect the reliability of video sampling. However, this fact does not facilitate biological interpretations on the basis of UWTV observations. It is noticeable that highly variable numbers of *Nephrops* were recorded on the tracks (respectively 385, 687 and 1369 individuals in 2014-2016). Those strong differences suggest that the biological cycle *a fortiori* by sex induces an impact to the seasonal and dial rhythm due to the process of reproduction and feeding. Higher numbers of *Nephrops* in July 2015 and in May 2016 could be attributed to more pronounced female activity outside burrows than in September 2014.

2 Interpretation from the trawl samples (2014 and 2015)

Trawling associated to the UWTV survey in years 2014 and 2015 aimed to estimate the proportion *Nephrops*/*Munida* as the second species seems to be able to live in other crustaceans’ burrows. The dial rhythm by species can be taken into account in order to analyse the relative abundance indices obtained by trawling.

The rough relative abundance indices for *Nephrops* and *Munida* for the whole area and by sedimentary stratum are presented in Table 4.

Table 4. Relative abundance indices (10^3 individus) for *Nephrops* and *Munida* obtained by experimental trawling in 2014 and 2015. Estimations by sedimentary stratum and for the overall area.

2014							
		Nephrops			Squat lobster		
stratum	stations	number	SD	CV(%)	number	SD	CV(%)
CB	6	1914	785	41.00	549	255	46.40
CL	5	22227	13175	59.27	7115	2544	35.76
LI	18	26779	13252	49.49	33842	17075	50.46
VS	5	7881	5336	67.71	1735	1117	64.38
VV	23	39290	11142	28.36	64307	23670	36.81
total	***57***	***98091***	***22415***	***22.85***	***107549***	***29319***	***27.26***

2015							
		Nephrops			Squat lobster		
stratum	stations	number	SD	CV(%)	number	SD	CV(%)
CB	4	2377	1259	52.96	263	171	64.87
CL	7	10650	4965	46.62	6374	3611	56.64
LI	22	12293	4199	34.16	6668	1790	26.84
VS	6	2917	2388	81.88	692	457	66.16
VV	10	8500	3724	43.81	22380	11637	51.99
total	***49***	***36736***	***7965***	***21.68***	***36377***	***12324***	***33.88***

The table 4 shows similar magnitudes for both species by year with generally stronger uncertainties (CVs) for *Munida* represented by a higher number of samples with zero individuals. The huge difference between years by species (almost three times lower indices in 2015 than in 2014) is unlikely: in the case of *Nephrops*, many indicators (LPUE, landed and discarded numbers) suggest a steep increase between 2014 and 2015. This fact stresses a point to the not pertinent contribution of the experimental trawling, therefore the trawl sampling was interrupted from 2016 onwards. Although, the total numbers of *Nephrops* and of *Munida* for each year are close even if there are some differences *vs.* sedimentary stratum as seen above.

The high proportion of *Munida* has to been analysed because it may induce bias in the burrow counting. That can be caused either because of confusions linked to the shape of burrows (exclusively under bad visibility conditions rarely seen in the Bay of Biscay surveys) or because of a colonisation of *Nephrops* burrows by *Munida* (called "squat lobster" [2]).

As underlined in the previous § involving in the 2014's data, *Munida* is more active than *Nephrops* in different time intervals within a day. In September 2014, 385 *Nephrops* were observed during the overall survey (respectively 180 and 205 inside et outside burrows) against 2653 *Munida*. In July 2015, 687 *Nephrops* were counted (respectively 277 and 410 inside et outside burrows) against 1387 *Munida*. As regards with that, the catchability of bottom trawl may be stronger in the case of *Munida*. The relationships between the two species according to the spatial scale (*vs.* type of sediment) and according to the temporal one (*vs.* season, time interval within a day) are complex.

[2] squat (live)= to live in an building or area of land without the permission of the owner

2.1. *Spatial correlations Nephrops/Munida.*

Spatial correlations of numbers of burrows *vs.* numbers of caught *Nephrops* or *vs.* cumulated numbers of caught individuals for both species were studied. The independent and dependent variables were transformed by weighting the numbers cited above inversely to the distance between coordinates of video tracks (for numbers of burrows) and those of trawl hauls (for numbers of caught individuals). By this way, 55 and 49 pairs of values were proposed for 2014 and 2015 accordingly to the numbers of trawl stations with at least one caught individual.

The sampling plan applied on the 2014's trawl operations was a stratified random one in agreement with the protocol during the former LANGOLF-"Gwen Drez" survey 2006-2013 (which was included as tuning series for the XSA model for the FU23-24 stock after the IBP *Nephrops* 2012). In 2015, the sampling plan was a stratified pseudo-random one in order to develop the geostatistical processing on combined video/trawl data: on this basis, one video station on three was randomly chosen independently of the previous spatial allocation. This difference between sampling designs 2014 and 2015 is reflected in terms of fitting quality between numbers of burrows and numbers of *Nephrops* caught by the experimental trawl (fig. 4; R^2_{2015}=.4916 against R^2_{2014}=.1544). As consequence of that, the statistical explorations on trawl indices for *Nephrops* and *Munida* will mainly be focused on the 2015's data.

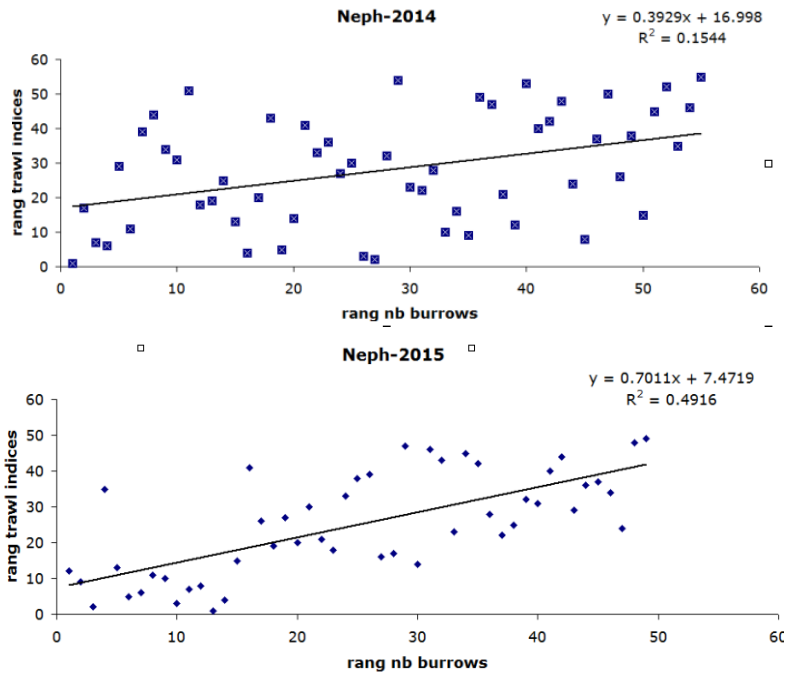
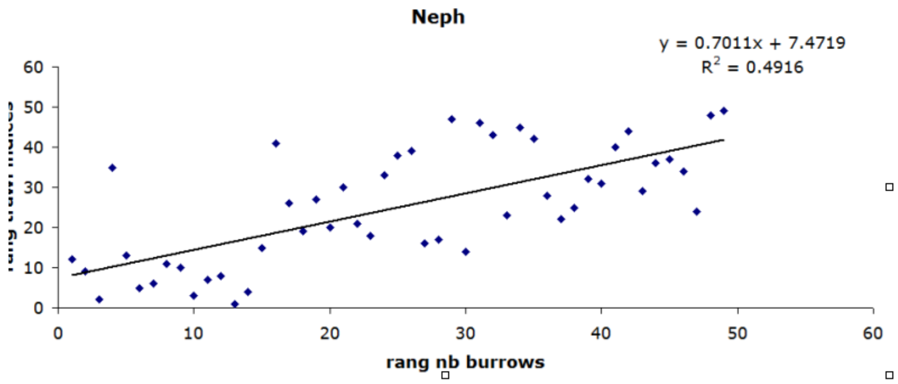


Figure 4. Rank correlations between number of burrows and trawl indices for *Nephrops*. Years 2014 (stratified random sampling plan for trawling) and 2015 (stratified pseudo-random plan modelled in connection with the systematic sampling plan for video stations).

In 2015, bootstrapped variables of numbers of burrows and of *Nephrops* are strongly correlated (R^2>.95), however this is due to the contribution of two pairs of values, thus this is a result caused by a geometrical artefact et does not correspond to an actual statistical robustness. The independent and dependent variables were replaced by their rank. This transformation was performed for the relationship between burrows and *Nephrops* and also for that between burrows and *Nephrops+Munida* (fig. 5).

Taking into account *Munida* in this exploration provides a higher level of correlation (R^2=.536 instead of R^2=.492, *i.e.* R=.732 instead of R=.701); the test t of Student between the correlation coefficients is not significant (t=1.464), but remains close to the critical value for α=.05.

The rank correlations were also tested on the 2014's data. The same type of transformations as for 2015 gave a correlation coefficient increasing when *Munida* are included in the total burrowing number of individuals (R=.393 with solely *Nephrops* against R=.460 with *Nephrops+Munida*).



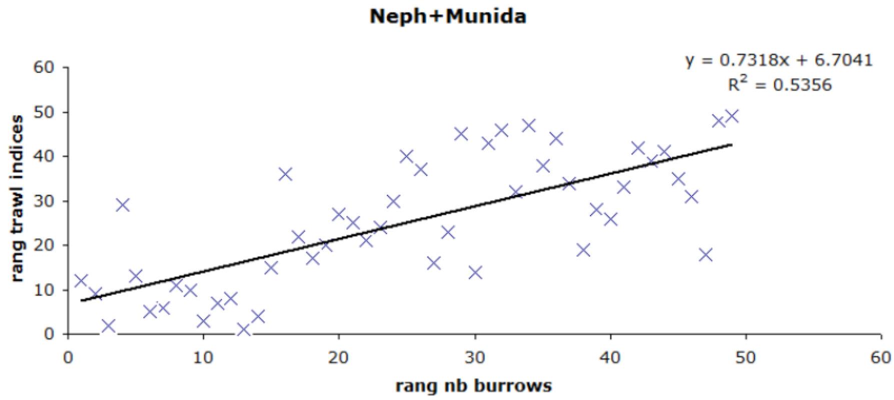
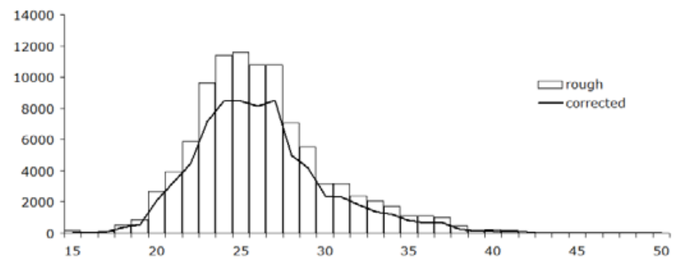


Figure 5. LANGOLF-TV 2015. Relationships between ranks of *Nephrops* number (above) and *Nephrops+Munida* (below) caught by trawl and number of burrows (the closest station of the UWTV survey; transformation and weighting inversely to the distance).

2.2. *Correction of the trawl indices according to the dial activity by species (2014 and 2015)*

Information provided on the video track and model fitted for the dial activity of each species (§1) is combined with the trawl indices accordingly to the time of trawling within a day by processing the adequate transformations *vs.* the sunrise or the sunset (§1). The trawl indices 2014 are corrected for *Nephrops* and for *Munida* (fig. 6; table 5).



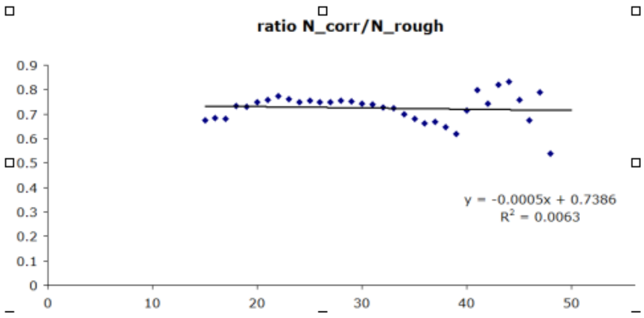


Figure 6. Left: LFDs (carapace length, CL in mm) obtained by trawling for *Nephrops* in 2014 (histogram: not corrected LFD ;; curve: LFD corrected by using the model for dial activity (§1). Right: relationship between *Nephrops* size (CL) and correction ratio accordingly to the time of fishing.

Table 5. Abundance indices 2014 estimated by trawling for *Nephrops* and *Munida*. Left: not corrected indices (see Table 4). Right: indices corrected *vs.* time of catch.

str	Munida	Nephrops	ratio	Munida	Nephrops	ratio
CB	549	1914	*3.486*	410	1150	*2.802*
CL	7115	22227	*3.124*	8919	21692	*2.432*
LI	33842	26779	*0.791*	21263	13683	*0.643*
VS	1735	7881	*4.541*	1291	4586	*3.553*
VV	64307	39290	*0.611*	55172	32142	*0.583*
total	**107549**	**98091**	***0.912***	**87055**	**73252**	***0.841***

The correction *vs.* the time of trawling causes a downwards revision for the *Nephrops* index with no significant effect on the LFDs of experimental catches (correlation almost zero between size and correction factor: fig. 6).

For both species the correction of abundance indices *vs.* time of fishing induces a reduction of values (-19% for *Munida*, -25% for *Nephrops*). The global ratio *Nephrops*/*Munida* does not change substantially (.841 after correction against .912).

On the 2014's data the use of such a correction factor strengths the rank correlations between number of burrows and number of burrowing crustaceans, either for exclusively *Nephrops* or for *Nephrops*+*Munida*. The conclusion that the correlations are higher when *Munida* individuals are added is still valid (table 6).

Table 6. Year 2014. Rank correlations between number of burrows and trawl indices (solely *Nephrops* [Neph] or *Nephrops*+*Munida* [Neph+*Munida*]

		N_rough	N_corr		N_rough	N_corr
Neph	ρ^2	0.154	0.192	ρ	0.393	0.439
				$\sigma(\rho)$	0.017	0.017
Neph+Munida	ρ^2	0.211	0.250	ρ	0.460	0.500
				$\sigma(\rho)$	0.017	0.016
				$t(\rho)$	2.771	2.602

At the opposite, the introduction of a correction factor on the 2015's data *vs.* the time of fishing provides an upwards revision of *Nephrops* indices by trawling as for this particular year the *Nephrops* activity on video track seems to be maximised during the night (table 3; fig. 3) whereas the trawling is conducted only during the day.

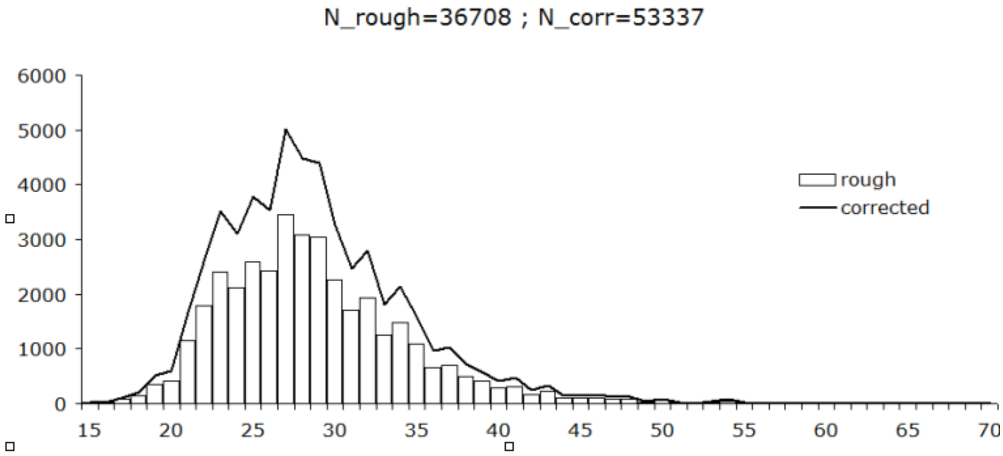


Figure 7 LFDs (carapace length, CL in mm) obtained by trawling for *Nephrops* in 2015 (histogram: not corrected LFD; curve: LFD corrected by using the model for dial activity (§1).

3 Synthesis

This WD analysed the interactions *Nephrops*/*Munida* which may affect the "species identification" coefficient. These explorations are independent of any possible confusion about the identity and shape of a *Nephrops* burrow reliably recognisable by the readers team: "1. crescentiform entrance. 2. Sediment ejecta and radial scrapings around entrance. Claw or perieopod indents. 'Drive-way' 3. Single to multiple entrances, focussing on an apparent 'raised' centrum".

The analysis involved in the UWTV data advantaged because of continuous recording on 24h/24. Additionally, information provided by experimental trawling (only for years 2014 and 2015) was also included in this study.

Video allows to investigate the basic differences of dial activities for both species: *Nephrops* is active during a more restrictive time interval within a day whereas the activity of *Munida* is more widely spread on 24 h. The intuitively expected case of *Nephrops* activity around dawn and dusk was observed on data collected in September 2014 and May 2016, although 2015's data presented a different profile. The change of season between the three UWTV surveys does not allow to have a deeper investigation on this point, but the statistical robustness for the fitted models has to be underlined.

Trawling provides weak useful information apart from the fact that the indices for both species are close for each year. Even after the correction of the trawl indices by including the model of the dial activity the ratio *Nephrops*/*Munida* remains stable. Trawling does not give any information on the occupancy rate of *Nephrops* burrows by *Munida*. Nevertheless, there is a signal shown by the increase of the rank correlations when *Munida* is included in the whole crustacean burrowing instead of exclusively *Nephrops*.

Study and assessment of the Bay of Biscay *Nephrops* on the basis of UWTV survey

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1 Introduction.

1.1 International context.

Reports of the WKNEPHTV in 2007 and WKNEPHBID in 2008 (anon, 2007; 2008) laid the foundations for a standardised use of the UWTV at the aim of counting reliably the *Nephrops* burrows and providing analytical assessments for the routinely UWTV surveyed stocks. A yearly ICES working group (WGNEPS) is carried out to analyse methodology for the UWTV assessments (latest WG: anon, 2015).
The firstly studies of *Nephrops* stocks using UWTV tools were undertaken in Scottish waters in the early 90's. These first experiences aimed to improve knowledge on the *Nephrops* behaviour and to quantify several biological parameters for the species and were not connected with the stock assessment process. For the *Nephrops* stocks, the depth distribution is negatively correlated with the latitude: therefore some Scottish stocks spread in a relatively shallow waters (depth range of 20-25 m; 80-120 m for the Bay of Biscay) are advantaged to examine by diving the distribution and the structure of burrows (diameter, number of openings). Those studies are still used as reference to parameterize by analogy other *Nephrops* stocks more deeply distributed.
For the major part of UWTV surveyed stocks reference points are defined (Fmsy and HR) and the stock assessments are analytical whereas for a minor part of them (mainly because of inaccurately defined boundaries and actual surface or poorly conducted sampling for landings and discards) the UWTV results are used for a DLS method specifically defined for *Nephrops*.

1.2 Feasibility of the Bay fo Biscay UWTV survey and specific goals.

The UWTV survey named "LANGOLF-TV" conducted since 2014 aimed to demonstrate the technical feasibility of such a survey in the local context and to identify the necessary competences and equipment for its sustainability. During the first two years, 2014 and 2015, video sampling was associated to a trawl one for the purpose of providing *Nephrops* LFDs by sex and estimating the proportion of other burrowing crustaceans (mainly *Munida*) which can induce bias in the burrows counting.
The assessment method based on UWTV data requires an unbiased and accurate calculation of the actual surface of the stock and, moreover, available dataset linked to the population dynamics (LFDs by sex for landings and discards). Both criteria are satisfied in the Bay of Biscay.
The surface involving in *Nephrops* is precisely delimited owing two information: (1) on the sedimentary structure of the sea bottom (5 spatial strata; fig. 1 above); (2) on the systematic grid of video tracks combined with VMS data for the fishery (fig. 1 below; data

source: National Fisheries Direction; compilation: Ifremer). Sampling of landings and discards (onboard and at auction) has provided yearly dataset since 1987 and mainly since 2003 owing to the monitoring of the European DCF plan (table 1; fig. 2).

Under these favourable conditions, the Bay of Biscay stock seems to be appropriate for an UWTV survey and analytical assessment.

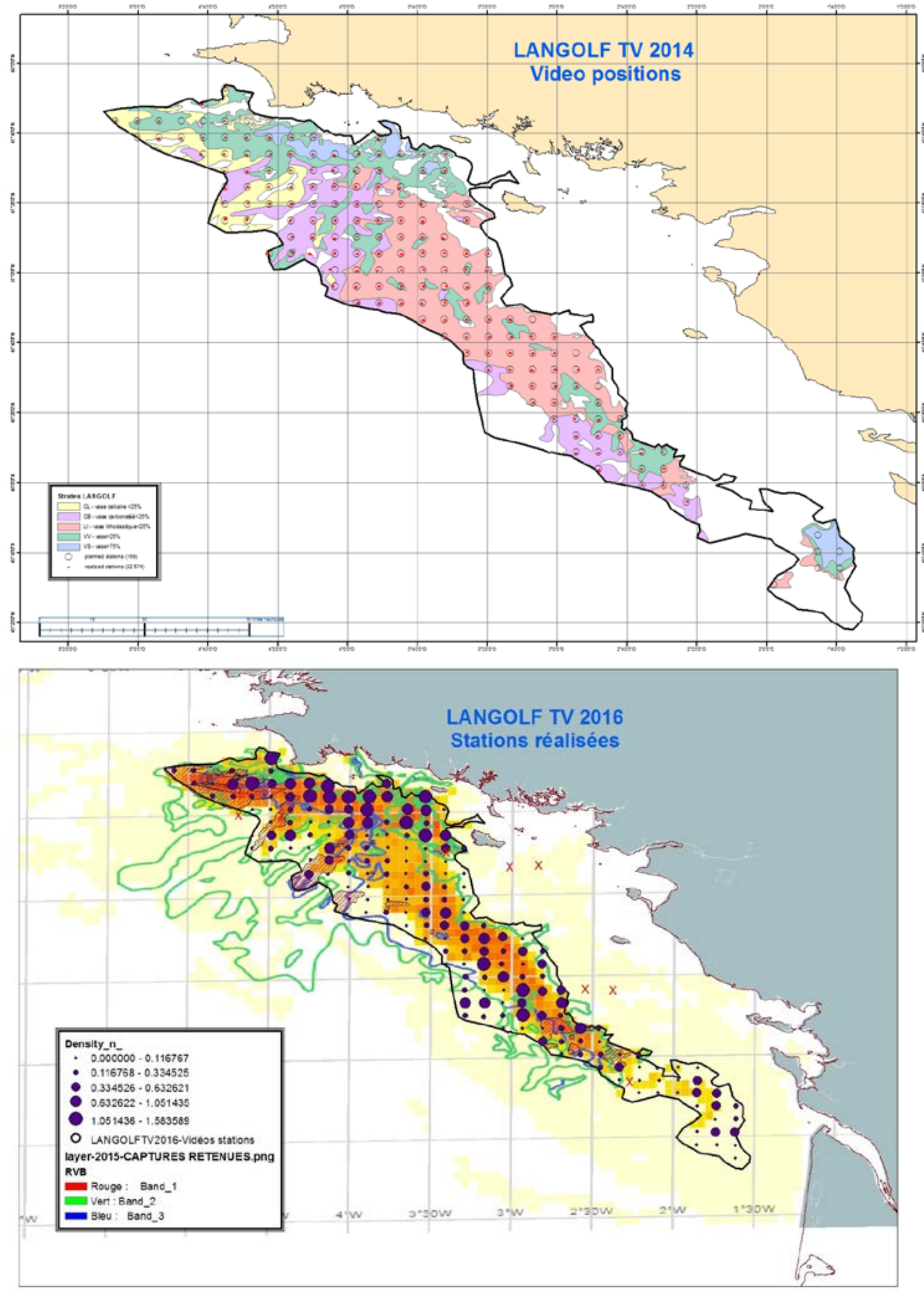


Figure 1. Above: spatial stratification of the Bay of Biscay according to sedimentary criteria (see details §1.3). Below: UWTV stations on a systematic grid (example of the year 2016) and VMS data for retained catches of *Nephrops* (example of the year 2015; source: National Fisheries Direction; compilation: SIH Ifremer).

Table 1. *Nephrops* in the Bay of Biscay (VIIIab). Above: Landed and discarded weights. Below: Discards and landings in numbers (10^3 individuals) obtained by sampling onboard and at auction.

Year	Landings (1)					Total Discards		Catches
	FU 23-24 (2)	FU 23	FU 24	Unallocated (MA N)(3)	Total VIIIa,b	FU 23-24		Total
	VIIIa,b	VIIIa	VIIIb		used by WG	VIIIa,b		VIIIa,b
2003	1	3564	322	49	3886	1977	*	5863
2004	na	3223	348	5	3571	1932	*	5503
2005	na	3619	372	na	3991	2698	*	6689
2006	na	3026	420	na	3447	4544	*	7990
2007	na	2881	292	na	3176	2411	*	5587
2008	na	2774	256	na	3030	2123	*	5154
2009	na	2816	212	na	2987	1833	*	4820
2010	na	3153	245	na	3398	1275	*	4673
2011	na	3240	319	na	3559	1263	*	4822
2012	na	2290	230	na	2520	1013	*	3533
2013	na	2195	185	na	2380	1521	*	3900
2014	na	2699	108	na	2807	1326	*	4133
2015	na	3425	144	na	3569	1492	*	5061

Year	*Discards*	*Landings*	*% discarding*
1987	268 244	288 974	48
1991	151 634	217 338	41
1998	150 995	161 549	48
2003	201 841	152 485	57
2004	222 089	139 753	61
2005	315 346	166 165	65
2006	487 288	127 942	79
2007	214 788	117 273	65
2008	198 031	115 274	63
2009	174 480	123 504	59
2010	113 530	138 120	45
2011	121 603	108 011	53
2012	117 935	101 424	54
2013	154 914	114 853	57
2014	117 930	121 594	49
2015	156 400[1]	138 921	53[2]

1.3 The Bay of Biscay Central Mud Bank.

The studied area called "Central Mud Bank" occupies around 11 680 km² and was described by Dubrulle *et al.* (2005), Bourillet *et al.* (2006); the specific aspects of its ecosystem were analysed by Le Loc'h (2004). Around 100 m of depth, generally comprised in the range 70-120 m, this area is wide up to 150 km in the Northern part and it is shrunk (~25 km) in the Southern limits. The muddy layer formed in the 2nd ice period is generally thin (0.5-1.5 m) apart from the extreme Northern part (3 m). The overall outline is fixed

[1] Provisional estimation (of the WGBIE 2016 upwards revised: 156 400 thousands individuals discarded instead of 128 712).
[2] 53% of discard rate (instead of 48%) after the upwards revision for discards.

according to information of previous sedimentology studies combined with information linked to commercial fishing activity (*e.g.* VMS).
Five sedimentary strata *vs.* the mud composition of the sediment and its origin are defined (Fig. 1):

(1) >25% mud (abbreviation VV)
(2) >75% mud (abbreviation VS)
(3) Lithoclastic mud<25% (abbreviation LI)
(4) Carbonate mud<25% (abbreviation CB)
(5) Calcareous mud<25% (abbreviation CL)

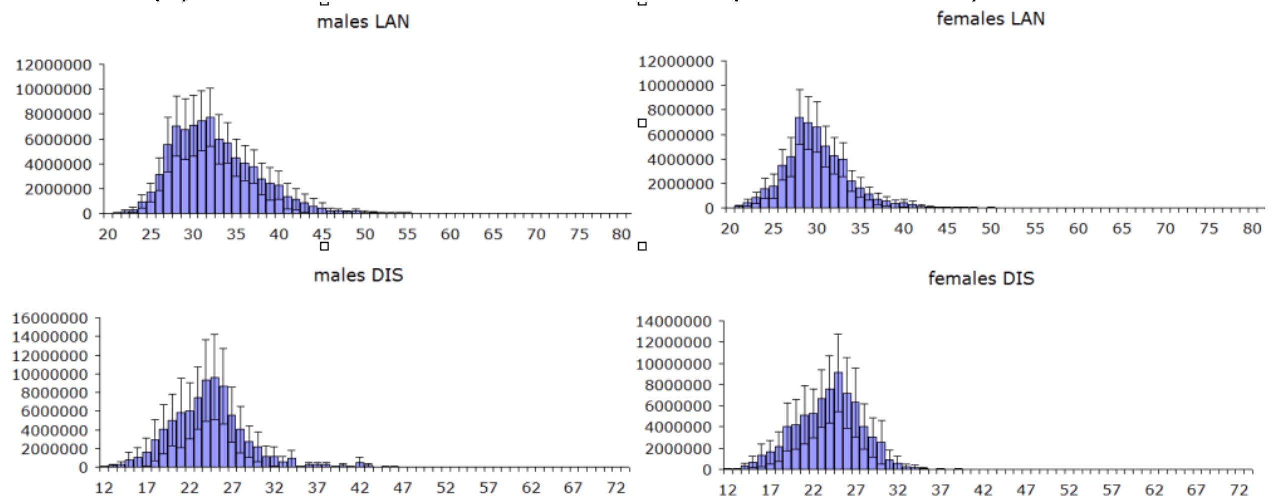


Figure 2. LFDs (size in carapace length, mm) for landings and discards by sex . Example of dataset 2015.

1.4 Description of the UWTV surveys (2014-2016).

1.4.1. Vessels and equipement.

In 2014 and 2015, LANGOLF-TV was carried out on 10 actual days associated to experimental trawling stopped thereafter whereas in 2016 the UWTV survey took place during 12 days. For each year six scientists participated on the onboard work. As the project was planned owing to a partnership with the "Marine Institute" (Republic of Ireland) one expert scientist and one electronics technician from Ireland joined the team.

Table 2. The LANGOLF-TV surveys 2014-2016.

Year	*Vessel+actual duration*	*Dates*
2014	Celtic Voyager (10 days)	20-29/09
2015	Prince Madog[3] (10 days)[4]	20-29/07
2016	Celtic Voyager (12 days)	04-15/05

For the three surveys, the equipment (sledge, computing hardware, screens, recorders) were provided by the "Marine Institute". The sledge is based on the Scottish material (2.5 m*2.7 m*2.5 m; weight=80 kg); its speed is around 20 m/min.

[3] In 2015, "Prince Madoc" replaced the initially planned "Celtic Voyager" because of major technical problems.
[4] In 2015, two sampling days were lost due to bad meteorological conditions.

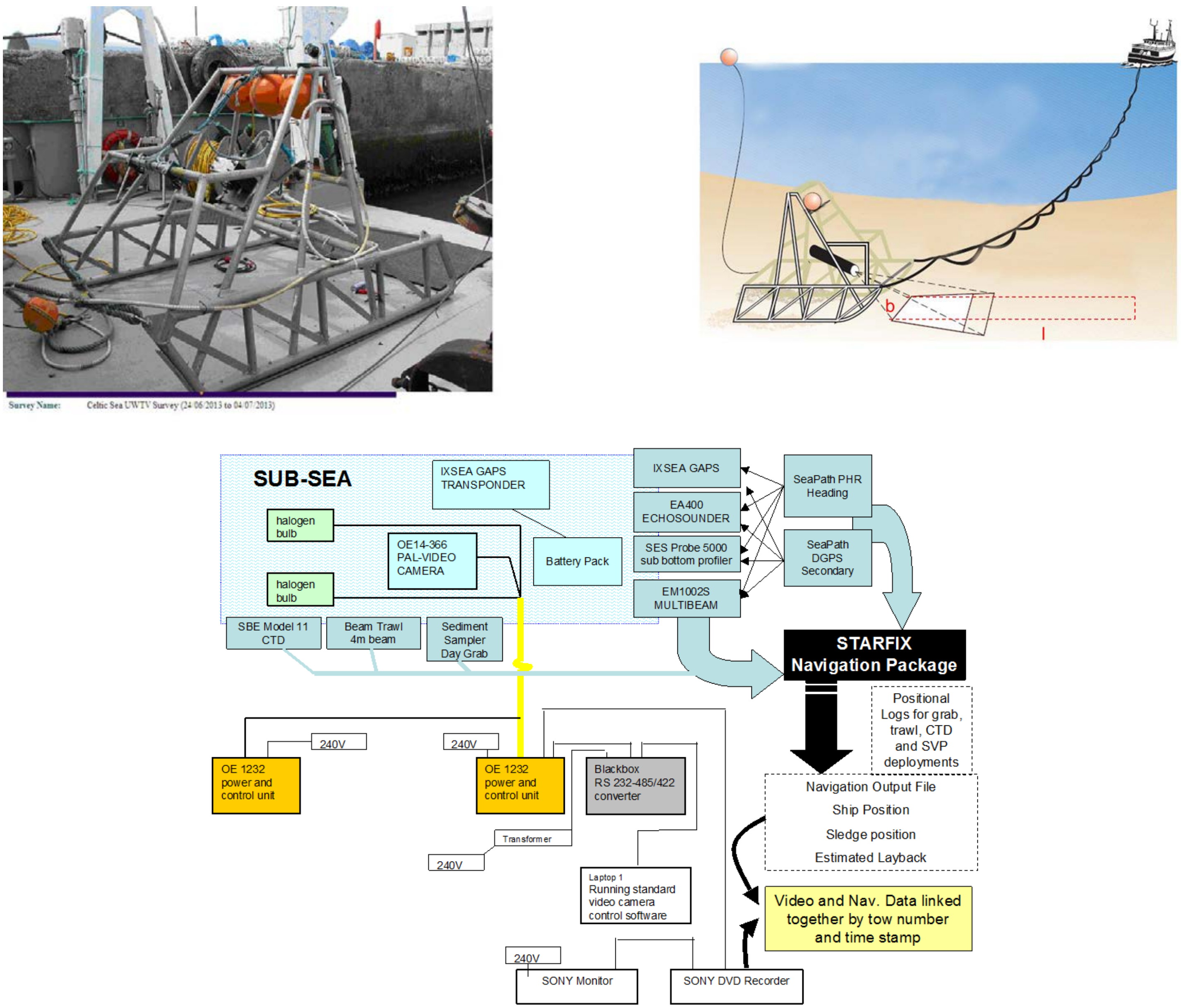


Figure 3. Schematic diagram of the sledge and traction on the sea bottom. Mechanism for acquiring process onboard. *Source: Marine Institute, Ireland.*

1.4.2. Counting protocol

In conformity with the recommendations of the SGNEPS (anon, 2010) any new reader has to attend a training course in order to recognize the *Nephrops* burrows by avoiding possible confusions with other burrowing crustaceans structures. The main features for that are described during the WKNEPHTV in 2007 (anon, 2007).

After this preliminary stage, a reading test on 10 videos of 5 min is carried out. The provisional absence of reference footage in the Bay of Biscay implies the use of other support coming from grounds with similar conditions (density of burrows) to the Bay of

Biscay: the Smalls grounds (FU22, Celtic Sea, UWTV surveyed since 2006) was chosen. A validation by the test CCC (fig. 4) allows to decide on the conformity or not of each reader.

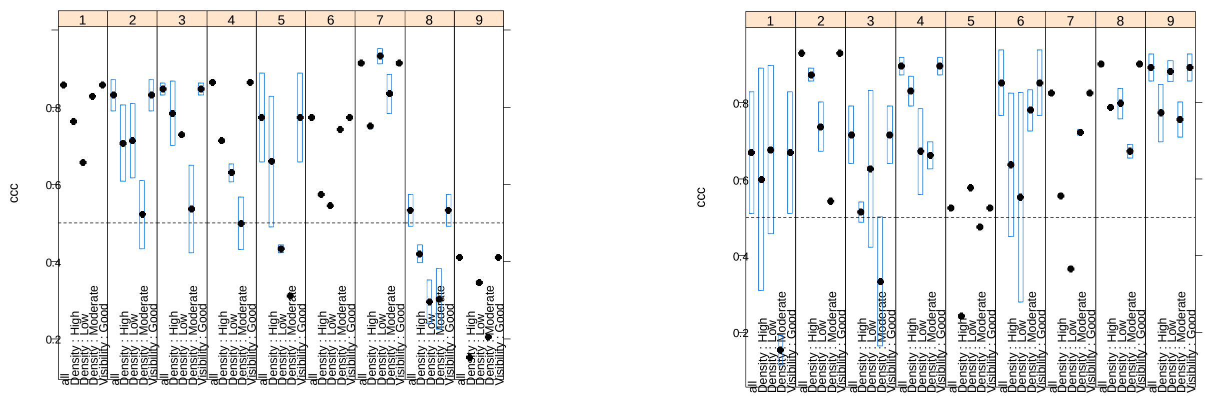
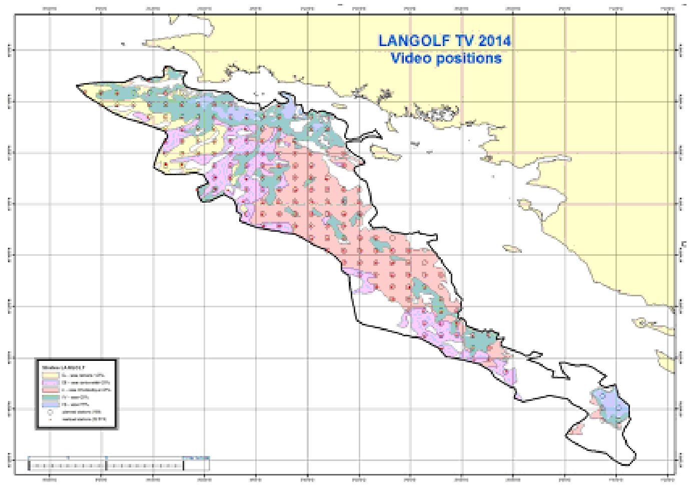


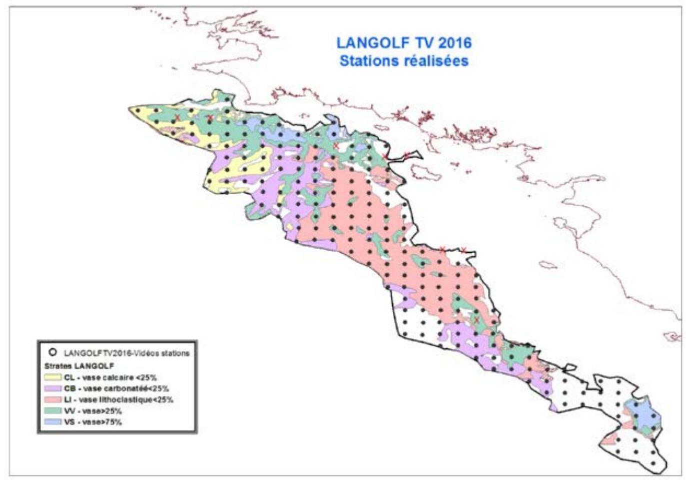
Figure 4. Conformity test CCC (reference footage: Smalls ground, FU22) . Left: year 2014. Right: year 2015.

Acquiring images on the sea bottom requires a preliminary use of multi-beam sounder aiming to determine the nature of the sediment and to avoid technical problems due to rough ground. The recording starts when the sledge reaches the adequate speed (~0.8 knots), the contact with the sediment is conform and the visibility is satisfactory. Recording lasts 10 min even with no *Nephrops* burrows on the track; 7 min minimum are necessary for the validation of the footage.

1.5 Sampling plan.

In accordance with other routinely UWTV surveyed stocks (anon, 2009), the sampling protocol applied since 2014 has been a systematic one advantaged by wider spatialised explorations on collected data. A distance of 4.7 nautical miles was retained similarly to the FU22 Smalls Ground. 165 stations were planned per year: among them 156 were validated for 2014 (few tracks abandoned due to rough sea bottom) whereas for 2015 96 stations were sampled because of bad meteorological conditions (fig. 5). The problem was tackled in 2016 by a longer survey duration: 14 effective working days were planned and owing to favourable conditions 12 days were sufficient to complete the whole grid (204 stations carried out among them 196 validated). Moreover, this enabling context allowed to cover for the first time the area contained in the outline of the Central Mud Bank no belonging to any sedimentary stratum: this area known as not trawled due to rough sea bottom was sampled by 36 validated stations completing the 160 stations of the five strata.





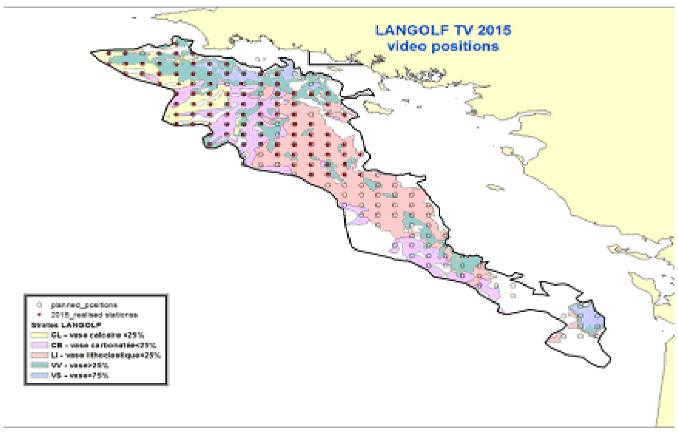


Figure 5. UWTV stations in the Bay of Biscay. Years 2014-2016.

2 Results.

All results of reading the footage by pairs of readers were analysed for the purpose of testing the conformity (fig. 6). Above diagonal: the quality of linear regressions reflects the conformity by pair of readers; below diagonal: deviations compared to the linear regression allow to watch differences between readers.

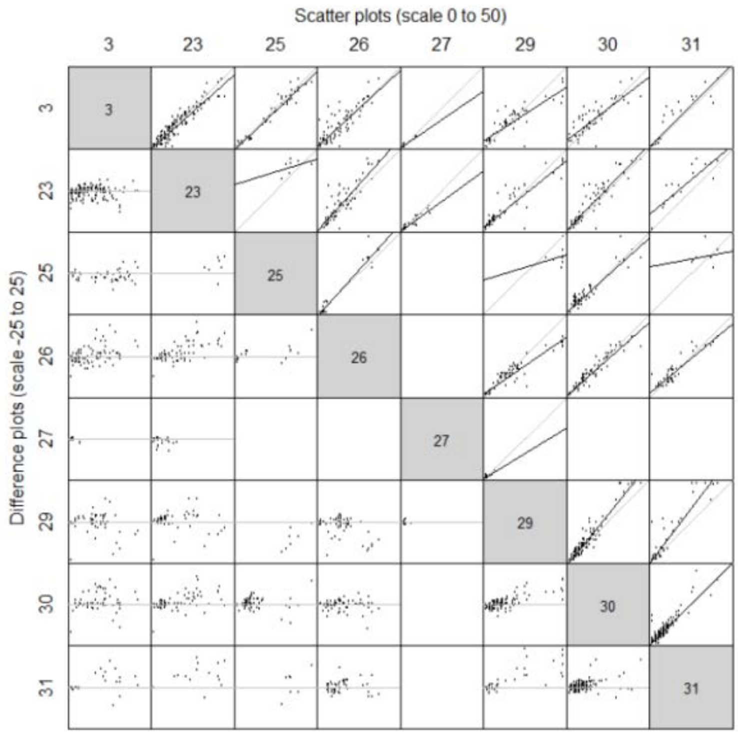


Figure 6. Tests of concordance by pair of readers. Example of the year 2015.

2.1 Stratified estimator.

2.1.1. Method.

More details can be found in Cochran (1977), Frontier (1983). The stratified sampling plan allows to calculate a ratio estimator (noted Y) of two variables, the numbers of burrows by video track and the surface of the track:

$$Y = \sum_{h=1}^{ns} Y_h = \sum_{h=1}^{ns} S_h . \frac{\sum_{i=1}^{nh} x_{ih}}{\sum_{i=1}^{nh} s_{ih}}$$

with:
h= stratum [h=1,...,ns] (ns=5 or 6); i= station by stratum h [i=1, ..., n_h]; S_h= total surface of the stratum h; s_{jh}= surface for the station i, stratum h; x_{ih}= total number of burrows by

station i in the stratum h (by adding the total recorded and validated minutes by station averaged according to the number of observers usually equal to 2)[5]

The variance of Y, noted V[Y], is given by:

$$V[Y] = \sum_{h=1}^{ns} V[Y_h] = \sum_{h=1}^{ns} \left[\frac{S_h}{\sum_{i=1}^{nh} s_{ih}} \right]^2 \left[nh.\left(\frac{Y_h}{S_h}\right)^2 .V[s_{ih}] + nh.V[x_{ih}] - 2.nh.\left(\frac{Y_h}{S_h}\right) Cov[x_{ih}, s_{ih}] \right]$$

with $V[x_{ih}]$, $V[s_{ih}]$ and $Cov[x_{ih},s_{ih}]$ variances and covariance of x_{ih} and s_{ih}.

2.1.2. Results.

Raising to the five sedimentary strata.

As written above (§1.5), the whole area of the five strata was covered in 2014 although only 2/3 of the total number of stations were carried out in 2015. In 2016 100% of the Central Mud Bank was sampled.
The overall trend involves in maximum densities in the extreme Northern limit of the area. As explained below (§2.3) on geostatistical investigations, this point could theoretically be a disadvantage for the accurate definition of the stock boundaries. Table 3 shows results of raising for years 2014-2016 of burrow densities (/m²)[6]associated to their CVs by stratum.

Table 3. Total number of burrows (10^6), densities/m^2 and CVs by spatial stratum and for the whole area. Years 2014-2016.

	2014 (156 stations)				2015 (96 stations)				2016 (160 stations)				
	nb/m²	total burrows	CV (%)	% burrows	nb/m²	total burrows	CV (%)	% burrows	nb/m²	total burrows	CV (%)	% burrows	% surf
	0.442	**5164.53**	**5.82**		**0.386**	**4501.89**	**8.25**		**0.386**	**4505.52**	**7.86**		
CB	0.317	802.68	15.68	15.54%	0.151	383.85	25.66	8.53%	0.258	654.41	19.84	14.52%	21.72%
CL	0.171	196.72	28.30	3.81%	0.306	352.28	18.57	7.83%	0.237	272.72	20.87	6.05%	9.87%
LI	0.354	1651.31	8.69	31.97%	0.320	1492.89	16.38	33.16%	0.283	1319.12	13.86	29.28%	39.94%
VS	1.656	1048.72	11.05	20.31%	0.875	553.75	30.48	12.30%	0.839	531.18	17.92	11.79%	5.42%
VV	0.544	1465.10	13.19	28.37%	0.639	1719.13	10.99	38.19%	0.642	1728.09	14.52	38.35%	23.05%

The average burrow density decreases (-13%) between 2014 and 2015, then remains stable in 2016. As the covered area in 2015 does not represent the overall one this result has to be interpreted cautiously. It is noticeable that the nominal statistics validated by ICES (WGBIE 2016: see anon, 2016) stressed a point to the steep increase of some stock indicators between 2014 and 2015 (2807 t landed in 2014 against 3569 t in 2015; LPUE of the tuning fleet GV-Q2: 12.3 kg/h in 2014 against 19.5 kg/h in 2015).

The burrows counting underlines the spatial heterogeneity of the Central Mud Bank: 50% of burrows are concentrated on 28% of the total surface. Some investigations (Fifas *et al.*, 2016) showed that the *Nephrops* directed fishing effort presents similar trend: 28% of the whole area involve in 66% of the fishing effort.

[5] The stratified estimator was also investigated under a sub-sampling plan (primary unit: station; secondary unit: observer*minute). It was proved that including the 2nd level increases the total variance only by 1.8-2.2%; thus, the stratified plan is further developed on only one sampling level.
[6] Rough results not yet corrected by the cumulative bias factor.

Strata with more compact sediment (VS, VV) are characterized by high densities close to the maximum observed levels for other European stocks (Western Irish Sea FU15: 0.83 burrows/m² in 2014; Firth of Clyde FU13: 0.64 burrows/m² in 2014). On the overall spatial scale, with 0.40-0.45 burrows/m², the Bay of Biscay is ranged among the average level of the European UWTV surveyed stocks.

Raising to the restricted area sampled in 2015.

Comparisons of burrows densities are carried out by restricting the sampled area for 2014 and 2016 to that covered in 2015. The basic condition of the stratified design is respected as all five sedimentary strata were sampled: although, the total surveyed area was reduced (7935 km² instead of the actual 11676 km² of the Central Mud Bank) (table 4).

Table 4. Total number of burrows (10^6), densities/m² and CVs by spatial stratum and for the whole area. Years 2014-2016 after restriction to the area sampled in 2015 (7935 km² instead of 11676 km²).

	2014 (109 stations)				*2015 (96 stations)*				*2016 (102 stations)*			
	nb/m²	total burrows	CV (%)	% burrows	nb/m²	total burrows	CV (%)	% burrows	nb/m²	total burrows	CV (%)	% burrows
	0.417	**3305.64**	**7.91**		**0.396**	**3138.42**	**7.85**		**0.412**	**3266.09**	**9.98**	
CB	0.265	432.86	19.23	13.09%	0.151	247.63	25.66	7.89%	0.251	410.92	27.44	12.58%
CL	0.171	196.49	28.30	5.94%	0.306	351.86	18.57	11.21%	0.237	272.40	20.87	8.34%
LI	0.340	899.35	12.88	27.21%	0.320	847.72	16.38	27.01%	0.260	688.59	21.35	21.08%
VS	1.656	665.91	11.05	20.14%	0.875	351.61	30.48	11.20%	1.058	425.20	16.20	13.02%
VV	0.530	1111.04	17.90	33.61%	0.639	1339.59	10.99	42.68%	0.700	1468.99	17.20	44.98%

This raising scheme causes an increase of CVs for 2014 and 2016 because of the decrease of the sampled track numbers whereas 2015's CVs are slightly reduced as the actually sampled area of 7935 km² is more realistic than the whole Central Mud Bank surface.
More stability of estimates from year to year is obtained by this raising. Estimate for 2014 goes downwards (the Southern part excluded from this analysis was richer than the total average) although this one for 2016 grows (the Southern part was less abundant than the total average). The predominance of compact strata (VS, VV) strengthens.

Raising 2016 including the rough sea bottom.

The favourable weather conditions in May 2016 allowed to cover a supplementary area assumed to not be trawled as occupied by rough ground (Table 5).

Table 5. Total number of burrows (10^6), densities/m^2 and CVs by spatial stratum and for the whole area. Year 2016 after including rough sea bottom contained in the outline of the Central Mud Bank (16164 km^2 instead of 11676 km^2 for the five sedimentary strata *sensu stricto*).

	2016 (160 stations)				
	nb/m²	total burrows	CV (%)	% burrows	% surf
	0.386	**4505.52**	**7.86**		
CB	0.258	654.41	19.84	14.52%	21.72%
CL	0.237	272.72	20.87	6.05%	9.87%
LI	0.283	1319.12	13.86	29.28%	39.94%
VS	0.839	531.18	17.92	11.79%	5.42%
VV	0.642	1728.09	14.52	38.35%	23.05%

	2016 (196 stations)				
	nb/m²	total burrows	CV (%)	% burrows	% surf
	0.320	**5167.67**	**7.84**		
CB	0.258	654.41	19.84	12.66%	15.69%
CL	0.237	272.72	20.87	5.28%	7.13%
LI	0.283	1319.12	13.86	25.53%	28.85%
VS	0.839	531.18	17.92	10.28%	3.92%
VV	0.642	1728.09	14.52	33.44%	16.65%
RO	0.148	662.15	29.61	12.81%	27.76%

The additional area (noted RO[7]) is represented by much lower densities than the five strata (0.148 burrows/m² against 0.237-0.839 burrows/m²). However, on this rough ground crossed by some muddy channels there is a moderate fishing activity targeting *Nephrops*: that agrees with several VMS data (fig. 1) even if VMS remains valid on the whole trip duration scale but is not necessarily valid on the haul scale mainly for multi-purpose vessels operating for many days. In conclusion, even if densities on the rough sea bottom additional stratum are lower and the heterogeneity is strengthened (higher CV) it seems to be more appropriate to also include it in the UWTV investigated overall area.

2.2 Geostatistics.

2.2.1. Method.

Variogram.

More details are provided by Rivoirard *et al.* (2000). Two steps are generally distinguished in a geostatistical analysis: (1) the structural analysis aiming to describe and model the spatial structure of the variable (*e.g.* tools as variogram); (2) the use of this structure for a given evaluation problem (outcome such as global estimation and kriging).

The intrinsic approach considers that a regionalised variable can be described independently of the local geometry. This approach assumes the stationnarity of increments $Z(x+h) - Z(x)$ of a random variable with zero average $E[Z(x+h) - Z(x)]=0$ and a variance:

[7] RO=rough sea bottom

$Var[Z(x+h) - Z(x)] = E[(Z(x+h) - Z(x))^2] = 2\gamma(h)$

A model for the random variable is characterized by its variogram $\gamma(h)$. On the basis of the variogram, the variance can be calculated for any linear combination if .The experimental variogram calculates the mean variability by pairs of values separated to a distance :

$$\gamma^*(h) = 0.5\frac{1}{N(h)}\sum_{xi-xj\approx h}[z(x_i)-z(x_j)]^2$$

Global estimate.

In the instrinsic approach, the global estimate is given by the average density $Z(V) = \frac{1}{V}\int_V Z(x)dx$. If $Z(V)$ is estimated from an unbiased estimator $Z(V)^*$ and the variance is: $\sigma_E^2 = Var[Z(V) - Z(V)^*] = E[(Z(V) - Z(V)^*)^2]$

with two options: $Z(V)^*$ is the arithmetic mean $\frac{1}{N}\sum_i Z(x_i)$, $Z(V)^*$ is the weighted mean with associated to the kriging process.

2.2.2. Results.

The variographic analysis on the burrows densities revealed an anisotropy corresponding to the directions 45° and 135° *i.e.* orthogonal and parallel to the shape of the Central Mud Bank.

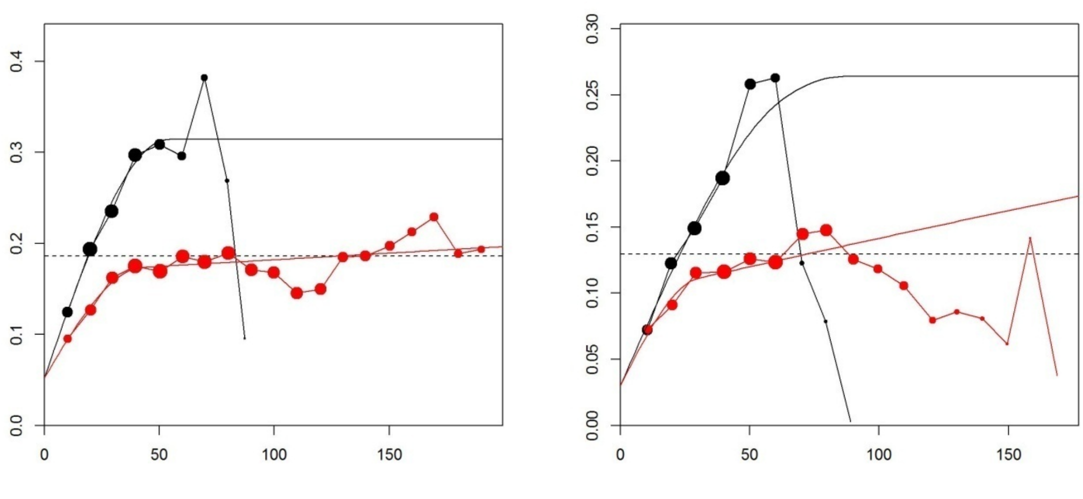


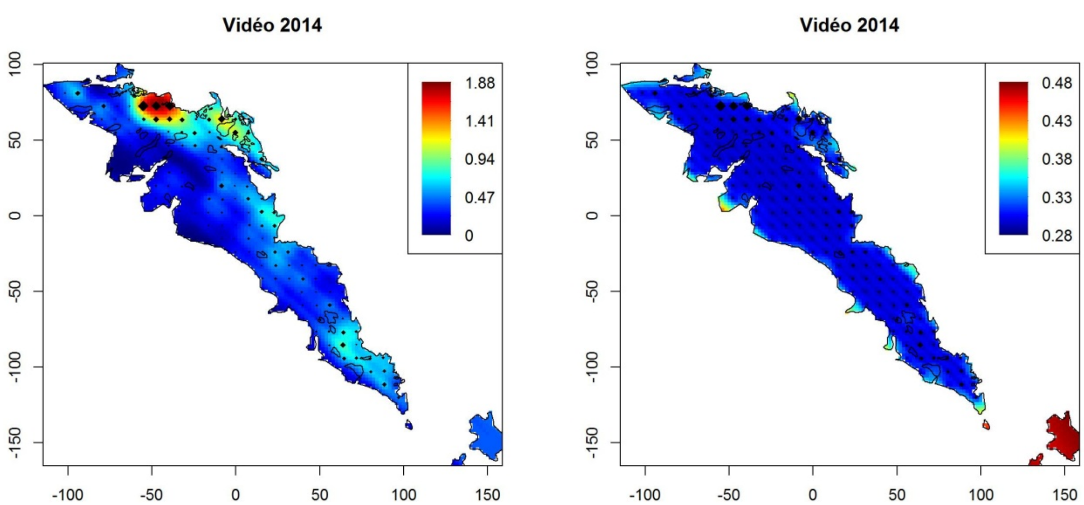
Figure 7. Experimental variograms (circles proportional to the number of pairs) and models (continuous curves) for the main anisotropic directions (red: NW->SE, black: SW->NE).

Year		2014		2015
Number of data	204	204	114	114
Method of estimate for average (A=arithmetic; KO=ordinary kriging)	A	KO	A	KO
Estimation	0.415930	0.425463	0.410321	0.414796
CV geo	0.052829	0.046598	0.180002	0.183475
CV iid	0.072647	-	0.082643	-
Surface (km²)	11 676	11 676	11 676	11 676
Abundance (Estimation * Surface)	4 856	4 968	4 791	4 843

Table 6. Estimation of the abundance of *Nephrops* burrows (10^6) by UWTV for years 2014 and 2015.

In 2014, the map produced on the basis of the ordinary kriging shows that the strongest densities for burrows (>0.94/m²) are located on the Northern part of the area (district of Le Guilvinec; Fig. 8). Intermediate levels of density (>0.47/m² and <0.94/m²) occupy the medium latitude of the Central Mud Bank (at the front of the La Loire estuary) and also in the Southern limit. The kriging error indicates the overall pertinence of the method with stable values apart from some patches (SD>0.38).

In 2015, the kriging error illustrates the partly surveyed area.



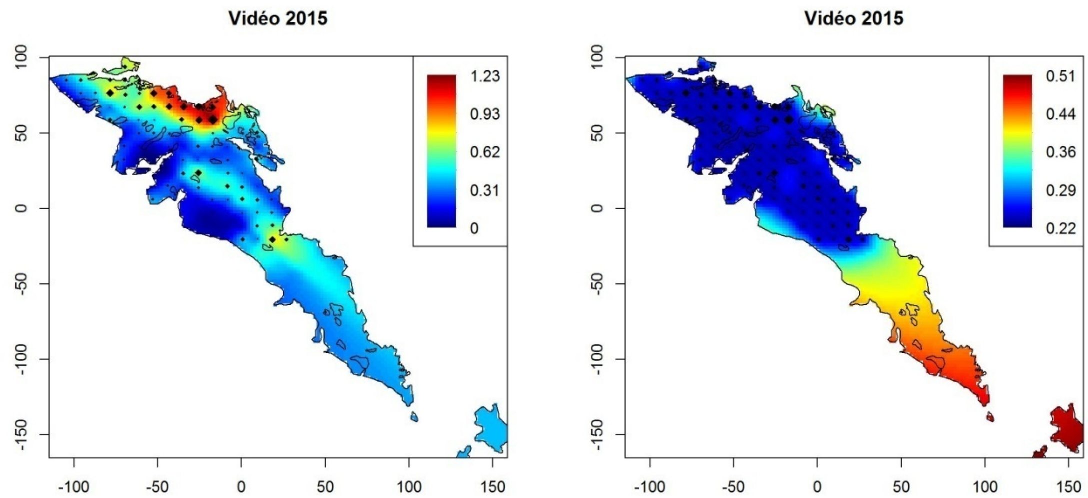


Figure 8. Years 2014 and 2015. Estimation of the burrows densities /m² using ordinary kriging (left column) error of kriging (right column).

2.3 Sources of bias.

The WKNEPHTV 2007 report (anon, 2007), provides detailed description of the bias sources: (1) uncertainty about the stock boundaries: a reply is given above (fig. 1) as the Central Mud Bank's outline seems to accurately define the stock limits; (2) edge effect correcting estimations according to the burrows entirely or not contained on the observation width; (3) detection rate associated to visibility conditions; (4) occupancy rate generally assumed equal to 1 (or 100%) because observations under enabling conditions (Scotland) showed that an unoccupied burrow is quickly filled by sediment; (5) confusion with other species burrows ("species identification"): some crustaceans (*Goneplax*, *Coelocaris*) or fishes (Gobiidae) are able to build structures in the ground and, additionally, other species such as *Munida* can use *Nephrops* burrows.

Edge effect.

The WKNEPHTV 2007 (anon, 2007) commented that the edge effect may induce overestimation of the actual number of *Nephrops*. Comparative analysis between stocks showed that the edge effect varies in the range 1.05-1.57. The correction factor does not seem to be correlated with the burrows density.

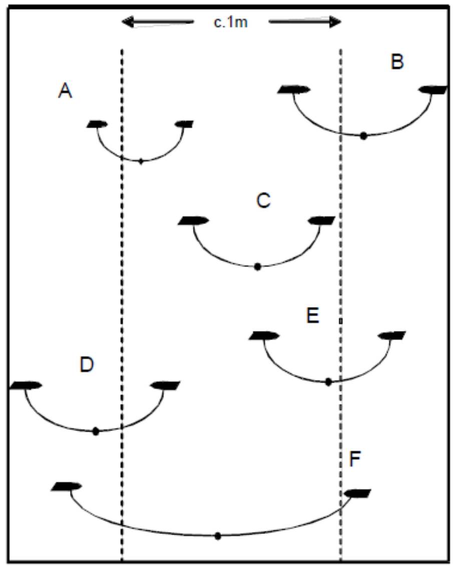


Figure 9. Illustration of the "two pass counting" method for the estimation of the edge effect correction factor.

The current knowledge level on the Bay of Biscay ground does not allow to model edge effect *vs.* all factors affecting the edge effect. The "two pass counting" method used by the "Marine Institute" presented in the report WGNEP2010 (anon, 2010) was applied in this study (see illustration in Fig. 9).

The correction factor due to the edge effect is calculated by (more details: anon, 2009):

$$R = \frac{S}{(S-E)/2+E}$$

with: R= correction factor; S= counting of all burrow complexes (1st reading); E= counting of burrows entirely contained in the observation width as defined by the lasers (2nd reading).

Uncertainty associated to this ratio estimator is calculated either by sedimentary stratum or for the overall Central Mud Bank. The variance V[R] is given by:

$$V[R] = 4.n.\frac{V[S].(1-R)^2+R^2.V[E]-2.R.(1-R).Cov[E,S]}{(\sum_{i=1}^{n}E_i+\sum_{i=1}^{n}S_i)^2}$$

with: variables E and S defined as previously; n= number of observations (station*min) of double reading.

Estimates of this correction factor were obtained by stratum and for the whole area. The re-sampled units tracks*minutes (2nd reading) were selected against sediment type and density level. A ratio estimator was preferred to an average of ratios because of its property to be convergent in probability.

Table 7. Method of "two pass counting" to estimate the edge effect by stratum and for the total area.

str	n	Σ 1st pass	Σ 2nd pass	R	σ[R]	CV[R]
CB	31	180.00	137.50	1.134	0.139	12.2%
CL	21	102.00	80.00	1.121	0.247	22.0%
LI	24	164.00	81.00	1.339	0.221	16.5%
VS	11	259.07	201.07	1.126	0.086	7.6%
VV	43	514.30	411.80	1.111	0.080	7.2%
total	***130***	***1219.37***	***911.37***	***1.145***	***0.065***	***5.7%***

The total estimator is equal to 1.145±11%. The ratios are similar for four strata on five (values 1.11-1.13). The singularity of the lithoclastic stratum could be explained by the size (diameter) of the burrow structures although this assumption cannot yet be confirmed. It is noticeable that the ratios by sample (by track*minute) are independent of densities (fig. 10).

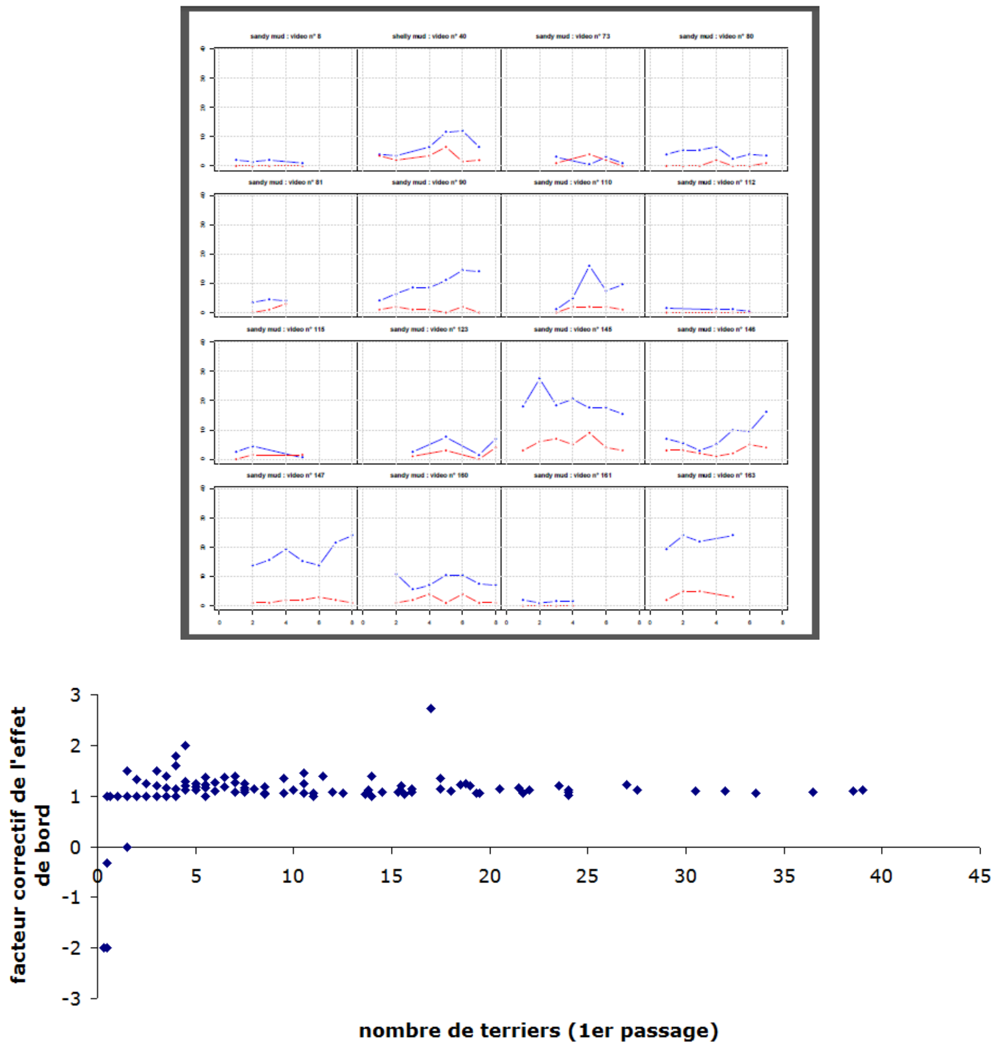


Figure 10. Above: comparison of burrow countings (1er reading onboard: blue curve; 2nd reading in laboratory: red curve) for different tracks *vs.* sediment nature. Below: relationship between numbers of burrows after the 1st reading (onboard) and the correction factor by track*minute after the 2nd reading.

Detection rate.

Visibility conditions for recording footage were optimum for the three surveys. Only two samples were cancelled throughout the whole period. We can note the problem caused for one track where reading was interfered with *Nephrops* directed trawling inducing sediment suspension. Irish experts advice to put off stations when fishing activity occurs nearby.

Sledge speed

Quick	Adequate	Slow	Variable	Sledge jump	Total
22	986	7	23	57	1095

The detection rate is calculated *vs.* visibility in the moment of image acquiring.

Good	OK	Ok to acceptable	Acceptable	Bad	Zero	Total
946	30	72	38	7	2	1095

The detection rate by minute*track (1095 observations during the survey 2014) is calculated by weighting by a factor comprised between 0 and 1. A value of 0.94 is provided for the Bay of Biscay.

Species identification (see WD XXX)

Three values are applied for the correction factor due to the *Nephrops*/*Munida* possible coexistence: 1.05, 1.10 or 1.15.

Number of openings by burrow

The number of openings by burrow is not used as input information for the counting which is based only on the total number of complexes. Involving in multiple entries, the footage analysis takes into account the orientation of openings according to their convergence or divergence (Fig 11). Trenkel *et al.* (2007) suggest an average number of openings by burrow equal to 3.4 however after excluding burrows with only 1 or 2 openings. An assumption can be formulated that a burrow has more than one openings because of necessity for the species to be adapted in the environment (avoidance of predation, ventilation for eggs). Simulations carried out by the "Marine Institute" integrate the number of openings in the calculation of the edge effect correction factor by assuming a Poisson density of probability for openings with values comprised between 1 and 4 whereas the diameter of a complex is simulated by a log-normal.

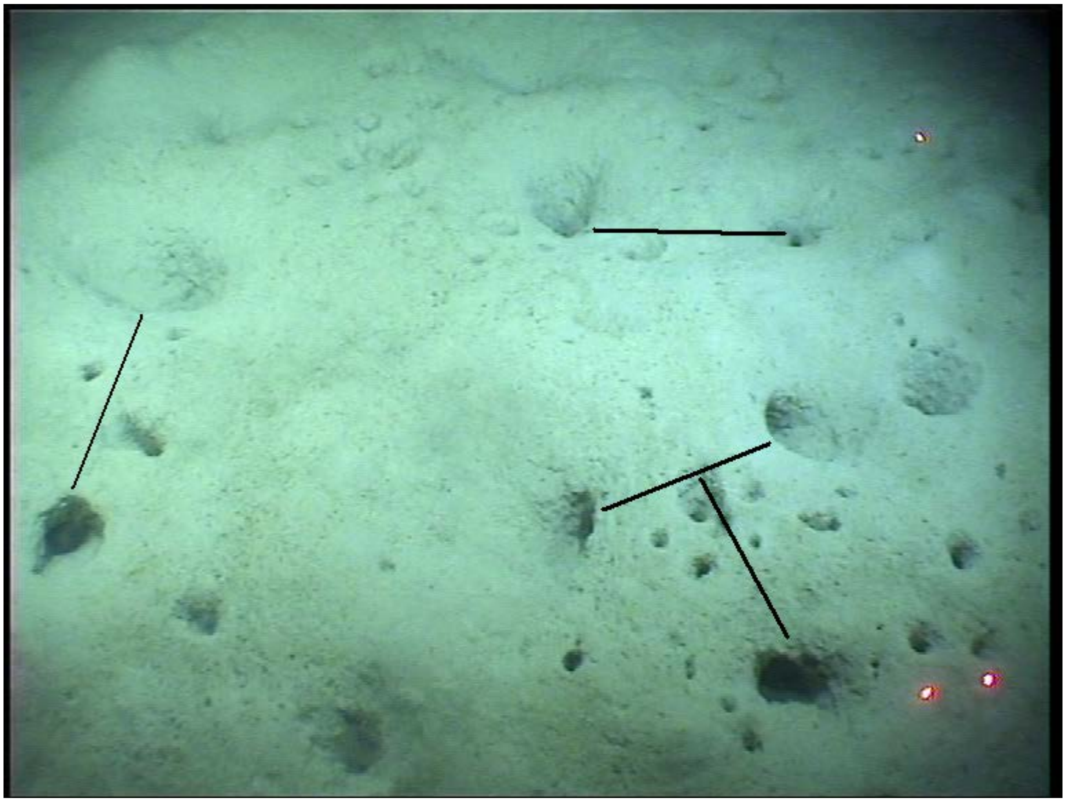


Figure 11. Illustration of *Nephrops* burrow complexes. Examples with 2 or 3 openings. Small round openings (in opposition to the shape for *Nephrops*) mainly in the lower right part correspond to *Coelocaris* burrows.

3 Discussion

3.1 Stratified estimates and geostatistics.

For the major part of routinely UWTV surveyed *Nephrops* stocks data are processed by geostatistics at the purpose of distinguishing the spatial structures and proposing map interface tools. Many stocks (*e.g.* Western Irish Sea, Smalls in Celtic Sea) are very homogeneous and variography provides unbiased results.

Nevertheless, for heterogeneous areas needing spatial sedimentary stratification such as the Bay of Biscay the optimum situation should be to cross geostatistics tools with the sedimentary structure as co-variable. For the stability and the precision of fitted variograms for all strata, it should be necessary to have high video track numbers on some reduced surfaces (such as the stratum VS) corresponding to high density levels. As a reminder, for years 2014-2016, 50% of burrows are concentrated on 28% of the total surface (strata VS, VV). Alternative medium-term possibility should be to fit multi-annual variograms for the different types of sediment. In the current transition stage, investigations on the two statistical approaches are suitable additionally because of the spatial variability of some correction factors.

3.2 Validity and improvement for the correction factors of bias.

Edge effect: the edge effect represented by a corrective coefficient of 1.15 is associated to a low uncertainty (CV=11%) with a substantial stability between strata excepted the stratum LI with a stronger value (1.34) possibly induced by the dimension (diameter) of the complexes. Re-reading of footage could confirm or not this interpretation. Moreover, comparison of ICES *Nephrops* stocks reveals strong discrepancy for this coefficient (anon, 2014) that needs standardisation of reading process.
Detection: a very good visibility characterized footage during the three years (in 2014, 946 minutes of reading on 1095, *i.e.* 86%, have high quality of image). However, calculation of a "detection rate" using ordinal variable (attribution of a score to the visibility) is not satisfactory: use of an adequate tool (*e.g.* disk Cecchi) should allow to quantify more accurately the effect of the turbidity on this factor. It is possible to be interfered with mobile gears: on 28% of the overall area with the highest density levels for burrows, are concentrated 66% of the total fishing effort.
Structure des terriers: the mean depth (80-120 m) prevents any investigation on field, thus the analogy with some Scottish stocks seems to be the more realistic solution.
Nephrops/Munida: see details in WD XXX. An optimum solution should be to examine and to count any type of crustacean burrow (on 3 species: *Nephrops*, *Munida*, *Goneplax*) and to provide relative abundance indices standardised *vs.* time within the day (*e.g.* midday) under the realistic assumption that the survey season should be thereafter fixed.

3.3 Synthesis of results.

Tables 8 and 9 below provide the main results of UWTV survey (correction factors, abundance indices) and attempt some preliminary explorations on the harvest rate. Calculations are carried out on the 2014's data[8]. Comparative values are given for the FU22 Smalls ground which was used as standardised stock reference.

Table 8. Correction factors for the number of burrows on the basis of the UWTV survey. Comparative examples between Bay fo Biscay and Smalls Ground (FU22).

FU	Stock	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
23-24	Gascogne	1.145	0.94	1.05	1	1.13
				1.10		1.18
				1.15		1.24
22	Smalls	1.35	0.9	1.05	1	1.28

[8] 2014 was chosen because the area sampled in 2015 does not represent the whole Central Mud Bank whereas 2016's nominal statistics and LFDs on landings and discards are not yet available.

Table 9. Input parameters for the "harvest rate"calculation,		
Landed numbers (10^3)	121 594	
Mean weight on landings (g)	23.08	
Survival rate (SR)	*0.30*[9]	*0.55*[10]
Dead discarded numbers(10^3)	82 551	53 069
Mean weight on discards (g)	11.25	
Numbers of removals (10^3)	204 145	174 663
Mean weight on removals (g)	18.30	19.49
Number of burrows (stratified statistics, 10^6)	5165	
Number of burrows (geostatistics, arithmetic mean, 10^6)	4856	
Number of burrows (kriging, 10^6)	4968	

On the basis of the values above the number of *Nephrops* burrows for the Bay of Biscay in 2014 is comprised in the interval 3916 and 4571 million individuals. Therefore, the preliminary estimate of the harvest rate taking into account different survival rate for discards should be between 3.82% and 5.21%.

4 Conclusion

The Bay of Biscay UWTV survey on the three years 2014-2016 demonstrated its technical feasibility for a representative covering of the whole area during 12-14 effective working days. The satisfactory sampling level for landings and discards and an accurate definition of the stock boundaries combining different sources of information (fine knowledge of the heterogeneous sedimentary structure, VMS data) have to be emphasized in order to analytically investigate the stock.

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Analysis of the biological sampling of *Nephrops* FU30 commercial catches

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During the last WGBIE, the *Nephrops* FU30 length frequency distributions were considered unsatisfactory to be applied in an analytical assessment (Vila and González-Herraiz, 2016). Therefore, the IEO was requested to describe the Spanish sampling plan of NEP30 commercial catches and try to improve it.

The pan-European biological sampling program of commercial fish catches evolved from a stock-based (DCR 2002-2008) to a métier-based sampling scheme (DCF 2009-now). Nevertheless, the on-board biological sampling of the Gulf of Cadiz trawl *métier* (OTB_MCD>=55_0_0) was not implemented in an appropriate manner. Due to the low catches of NEP30 stock, the concurrent sampling was applied but on trips selected for being directed to *Nephrops*. This anomaly was corrected in 2016, from when the sampled trips are randomly selected with replacement from the official vessel list of the Gulf of Cadiz trawlers, recording refusals.

It should be noted that the trawl *métier* operating in the Gulf of Cadiz is composed of 131 vessels, developing more than 21000 trips by year, and exploiting a high variety of species (crustaceans, cephalopods and demersal fish), among which *Nephrops* is number 25 in the ranking of landings. Moreover, the management of NEP30 follows a system of individual quotas in which any of those 131 trawlers is allowed to catch a small share of the TAC. This context, both the fisheries strategy and the NEP30 management, is a major challenge in the biological sampling of this stock, so that the random sampling was exceptionally reinforced in quarters 2 and 3 by sampling a number of trips targeting *Nephrops*, in order to meet the WKNEP requirements.

This paper presents the results of both sampling strategies, random and NEP-directed, to compare their respective sampling efforts, resulting LPUEs (used to provide scientific estimates of catches) and length frequency distributions (LFD). Firstly, unlike NEP-directed sampling, the random sampling with recording of refusals provides a probabilistic basis on which to calculate levels of bias. Secondly, NEP-directed sampling clearly overestimates the metier's LPUE so that, after being weighted to total effort, the resulting scientific estimates disproportionately exceed the historical level of harvest. Thirdly, none of the LFD obtained from the two sampling strategies provide sufficient quality to address an analytical assessment.

To sum up, the conclusions of this study are:

1. Sampling: to establish the random sampling as the basis of the biological sampling of commercial catches of the Gulf-of-Cadiz trawl *métier*.

2. NEP30 assessment: to provide scientific catch estimates to improve the current ICES assessment type (based on commercial LPUE).

3. EU-MAP: to maintain *Nephrops* in the species list for concurrent sampling of the Gulf-of-Cadiz trawl *métier*, although it does not exceed the EU-MAP threshold of 200 t.

Biological parameters in *Nephrops* FU 30 (Gulf of Cadiz)

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INTRODUCTION

Biological parameters are very important in the assessment of a stock. No analytical assessment has been carried out for *Nephrops* in FU30 and few or old information is available for this stock. The last length-weight relationship by sex was estimated in 2005 (Vila et al., 2005) and a sex combined length-weight relationship has been estimated recently (Torres et al., in press). Reproductive information has been analyzed only for female with data from 2004 (Vila et al. 2005; Vila et al., 2006), including the spawning season and the size at first maturity. Regarding to the Von Bertalanffy growth parameters no specific information exists for this stock. Length frequency distributions in FU 30 do not show clear modes and they are complicate to use. The identification of age groups and their mean lengths-at age as well as the estimation of the growth parameters in *Nephrops* proved to be difficult (Mytilineou et al., 1998). Castro et al. (1998) suggest that the modal progression analysis is not appropriated for this specie because the modes not progress in a manner that allows the following of a particular group. Tagging-recapture experience never has been proposed in FU 30 although it could be result problematic because *Nephrops* in the Gulf of Cadiz is distributed between 200 - 700 m of depth.

Under the DCF requirements for data collection (Reg. EC Nº 199/2008), samples have been provided for FU 30 since 2009. Nevertheless, it was difficult to obtain monthly market samples of *Nephrops* since 2012 and impossible in 2014 and 2015. The exhaustion early of the quota and the distribution of quota by vessel in these years made impossible to obtain samples for sampling in the laboratory. Additionally, data from annual trawl surveys routinely carry out in March and November are available. However, these months are out of the main spawning season and the individual weight information is not recorded onboard.

Owing the WKNEP2016 a recollect of the available data has been carried out and different biological parameters have been estimated (size maturity, length-weight relationship and the growth parameters in males and females) which can be used as inputs of the model proposed for the assessment of the *Nephrops* in FU 30.

MATERIAL AND METHODS

Data

Nephrops monthly samples were obtained from commercial bottom trawl catches landed in Sanlúcar de Barrameda port from 2009-2013 and 2016. Moreover, data from annual bottom trawl survey (IBTS) carry out in March and November for the period 2009-2016 were used in the analyses when it was relevant. For each individual sampled the carapace length (mm), total weight (g), sex and female maturity were recorded. Female maturity stages were assigned by macroscopic examination of the gonads based on the characteristics of the ovary (size, colour, texture) according to a five points scale proposed in ICES WKMSC (2009): Immature (Stage I:

transparent and thin ovary), Developing (Stage II: cream ovary), Maturing (Stage III: soft green ovary), Mature (stage IV: dark green ovary) and post-spawning (Stage V: whitish ovary). Ovigerous females were also recorded. The appendages masculina were collected from 2009 to 2016 (except 2011) and storage in ethanol 70% in order to obtain an estimates of the functional maturity in males according to McQuaid et al. (2002).

Size at Maturity

The size at which 50% (CL_{50}) of the females and males were mature was estimated by year and for the whole of the study period. Two criterions were used for mature females: Criterion 1 (stages II, III, IV, V and ovigerous) and Criterion 2 (stages III, IV, V and ovigerous). The spawning season was established in spring-summer (April-September) on the base of the monthly percentage of the different maturity stages (Vila et al., 2006).

The proportion of mature females and carapace length (CL) was fitted to a logistic model using a Generalized Linear Model (GLM) with binomial errors

$$P_i= 1-(1[1+\exp(a+bCL_i)]$$
$$CL_{50}= -a/b$$

where P_i is the relative frequency of mature females and CL_i is the size class.

The CL_{50} in females was estimated with INBIO R package (Sampedro et al., 2005), which uses non-parametric bootstrapping (1000 iterations) to estimate the Coefficient of Variation for the parameters' estimates.

The appendages masculina were measured to the nearest 0.1 mm using image analysis (NIS System software, version 2.3.3) since 2010 that allows measurements being made on a screen with more precision. In 2009, the classical method using a microscope with a calibrated ocular micrometer was used. The appendage masculina length was considered as the long measurement which gives the best fit to the CL according to the bibliography (ICES, 2013). The functional maturity in males was estimated using a segmented regression model fitted to a scatter plot of CL vs. appendage masculina length according to McQuaid et al., (2006). The change in growth rate of the appendage masculina was identified using the segmented regression function in R. This function searches for the optimal value from the dependent variable at which to split the series into two and returns the regression statistics for both lines with the breakpoint value itself.

Length- weight relationship

A non linear model with minimum least square adjustment (Gauss-Newton algorithm) was used to estimate the relationship between CL and total weight (W) for both sexes by year and for the whole of the study period using INBIO R package (Sampedro et al., 2005), according to the following equation:

$$W= a\ CL^b$$

Growth parameters

The empirical relationships to predict the Von Bertalanffy growth parameters for both sexes were used. The asymptotic length (CL_∞) was established following the equation of Pauly (1984) defined as $CL_\infty=CL_{max}/0.95$. The carapace length maximum (CL_{max}) was determinated by the highest CL observed in landings. The auximetric graph for *Nephrops* was used to derive the K growth parameter. The auximetric graph is a double logarithmic plot of K and L_∞ as ordinates and abscissa, respectively (Pauly et al., 1996). Thus, a population with a given set of growth parameters is represented by a single point, and different populations of the same species will trend to form a cluster of points. This cluster can be fitted with regression lines of known slope. The auximetric relationship was estimated for *Nephrops* using 30 sets of growth parameters (combined sexes) from this specie in the Mediterranean Sea (Apostolodis and Stergiou, 2008). In this study, 45 data set for each sex from three sources (Apostolodis and Stergiou, 2008, Palomares and Pauly, 2016 and ICES stocks annex from different FUs), which includes *Nephrops* from the Mediterranean Sea and Atlantic NE, were used to obtain the auximetric graph by sex (Table 1). The clusters were fitted to a linear regression. The K growth parameter in FU 30 was derived from CL_∞ and CL_{max}.

RESULTS AND DISCUSION

Size at Maturity

Table 2 shows the size at first maturity in females by year and for the total period (2009-2013 and 2016) using Criterion 1 and Criterion 2 depending on if females in stage II are considered mature or not.

When the Criterion 1 (stages II, III, IV, V, ovigerous) is used CL_{50} value ranged between 27.1 mm in 2010 and 24.9 mm in 2011. Both years covered the whole of the spawning season, the number of individuals used in the analysis was the highest and include individuals smaller than in the others years (20 mm CL in 2010 and 18 mm CL in 2011). Data were well fitted to the logistic model resulting in a low CV in both years (0.008 and 0.010, in 2010 and 2011 respectively). The worst fit was obtained in 2012 (CV=>2e+17) probably due to the low number of individuals as a consequence of the scarce months sampling and the few females with ovaries in stage I (immature). In 2013, the CV of the CL_{50} was low but in contrast the CV of the parameters a and b were very high (>5). The CL_{50} for all years pooled was estimated in 25.6 mm (CV=0.007).

CL_{50} estimates obtained using the Criterion 2 (stages III, IV, V, ovigerous) were always higher than when the Criterion 1 was used. The best fits resulted in 2010 and 2011 (CV=0.011 for both years) as the same occurred with the other criterion. CL_{50} was 29.2 mm in 2010 and 28.1 mm in 2011. The lowest CL_{50} was estimated in 2009 (26.2 mm) and the highest in 2013 (31.5 mm) but the CVs were higher (0.074 and 0.028, respectively). In spite of the CV of the CL_{50} was 0.013, a very high CV was obtained for the parameters a and b (>2) in 2013. The CL_{50} for all years pooled was estimated in 28.6 mm (CV=0.007).

Figure 1 shows the proportion of mature females by carapace length using Criterion 1 and Criterion 2 for the pooled data (2009-2013 and 2016) from commercial samples.

The size at first maturity in females in FU30 was previously estimated in 29.9 mm CL considering mature individuals when the ovary is in stage III or in more advanced maturity stages (Vila et al., 2005). This CL_{50} is according to the values obtained in this work using the Criterion 2. In FU 29 corresponding to the South of Portugal, close to FU 30 (Gulf of Cadiz), CL_{50} was estimated in 30 mm, ranging between 30.1 mm and 34.4 mm in the period 2003-2005 (ICES, 2006).

A histological study carried out in *Nephrops* FU 30 showed that the ovaries in stage II present oocytes beginning the vitellogenesis process (early vitellogenic oocytes) (Vila et al., 2012). These females will spawn over the spawning season so they should be considered as mature individuals. In that case, the estimation of the CL_{50} using the Criterion 1 would be more appropriated.

In the period analyzed in this document, the smallest females observed in stage II showed a CL of 23 mm and the smallest females with eggs in their pleopods showed a CL of 24 mm. This is information to take account.

The Figure 2 shows the split regression lines, breakpoints and standard error of the breakpoints yearly and with pooled data for the period analyzed (2009-2010 and 2012-2016). The appendage masculina length and CL relationship cannot be fit by segmented regression in 2009. Males smaller than 25 mm CL were scarcely represented in the sampling and possibly the measurement error of the appendage masculina was high because a microscope and calibrated ocular micrometer was used. In addition, a high dispersion of the data was observed this year. The breakpoint range between 25.9 mm CL in 2016 and 41.5 mm CL in 2015. Results are coherent yearly except for 2015 where the breakpoint is extremely high. The breakpoint for all years pooled was estimated in 30.7 mm CL (standard error=0.566).

The use of the appendage masculina to calculate size at onset of maturity was demonstrated and validate in other studies (Hillis, 1981; McQuaid et al., 2006). Estimates of size of functional maturity from morphometric chatacteristics are based on changes in the relative growth of a body part in relation to body size, such an appendage masculine and CL. The point at which change in relative growth occur, the inflexion point can be calculated by fitting regression lines to the data. The functional maturity in *Nephrops* males from different FUs in the Atlantic NE was analyzed in the framework of WKNEPH 2006 (ICES, 2006). In general, the breakpoint was estimated to be around 30 mm with differences in a couple of mm in some FUs. In Portuguese *Nephrops* from FU 29 the breakpoint was estimated in 28.4 mm.

Length-weight relationship

CL-W relationship for males and females estimated by year (2009-2013 and 2015-2016) and with all pooled data are showed in Table 3.

Figure 3 shows the CL-W relationship fitted for the whole period available for both sexes.

Growth parameters

The male with the highest CL observed in FU 30 was 62 mm in trawl surveys (1993-2015) and 63 mm in the historical landings (2000-2010) while 50 mm and 49 mm were observed in trawl surveys and landings, respectively. The asymptotic length (CL_∞) obtained from Pauly's equation using the higher CL observed resulted in 66 mm for males and 61 mm for females.

Figure 4 shows the auximetric graph that relates the growth parameter K and CL_∞ and their linear fit for both sexes. The *Nephrops* auximetric relationship for males and females were

$$\text{Log } K = -1.8614 \text{ Log } CL_\infty + 0.7526 \text{ (males)}$$
$$\text{Log } K = -1.2359 \text{ Log } CL_\infty + 0.0574 \text{ (females)}$$

The determination coefficients (r^2) were 0.56 and 0.31 for males and females, respectively.

K parameter derived from these fits using CL_{max} and the empirical CL_∞ were 0.184 and 0.167, respectively for males and 0.130 and 0.135, respectively for females. Table 4 summaries the results.

The K parameter obtained for males in FU 30 is quite similar with the obtained in some stocks of Ireland, Scotland or Portugal (see Table 1). However, the K parameter in FU 29 (South of Portugal) is higher than one derived in this document for FU 30. In these areas, the CL_∞ range between 60 mm and 73 mm. In the case of females, K parameter was generally according to K obtained in some Mediterranean stocks although they have a CL_∞ higher (66-77 mm) than in FU 30 (61 mm). In the South of Portugal (FU 29), CL_∞ is similar to females in FU 30 (65 mm) but K is lower (0.065) (see Table 1). In females, the low r^2 obtained in the auximetric analysis should be take account if the K parameter derived in this document is use.

CONCLUSIONS

Table 5 shows the biological parameters proposed for *Nephrops* in FU30 (Gulf of Cadiz).

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Table 1. *Nephrops* Von Bertalanffy growth parameters for males and females obtained from three sources (Apostolodis and Stergiou, 2008, Palomares and Pauly, 2016 and ICES stocks annex from different FUs) and used in the estimation of the K parameter and Asymptotic Length (CL_∞) in *Nephrops* FU 30 thought the auximetric analysis.

Males		Females		Country	Location
L_∞ (cm)	K	L_∞ (cm)	K		
12.08	0.060	8.18	0.100	Italy	Adriatic Sea
8.68	0.140	7.26	0.160	Spain	Alboran Sea 1
9.13	0.120	9.39	0.090	Spain	Alboran Sea 2
7.15	0.210	5.03	0.310	Portugal	Alentejo
6.15	0.280	4.50	0.380	Portugal	Algarve coast 1
6.55	0.270	4.53	0.420	Portugal	Algarve coast 2
8.34	0.130	7.07	0.120	Portugal	Algarve coast 3
6.00	0.160	5.60	0.080	Ireland	Aran Grounds (FU 17)
7.60	0.140	5.60	0.110	France	Bay of Biscay (FU23-24)
7.98	0.140	6.20	0.170	Algeria	Beni-saf 1
8.70	0.120	7.10	0.130	Algeria	Beni-saf 2
11.69	0.080	5.60	0.180	Spain	Biscay Bay
9.42	0.090	6.36	0.090	Spain	Catalan Sea 1
8.20	0.100	6.60	0.110	Spain	Catalan Sea 2
8.44	0.070	6.70	0.150	Spain	Catalan Sea 3
8.68	0.100	6.84	0.100	Spain	Catalan Sea 4
8.70	0.080	7.00	0.100	Spain	Catalan Sea 5
9.00	0.050	17.11	0.030	Spain	Catalan Sea 6
9.66	0.060	7.20	0.090	Spain	Catalan Sea 7
6.80	0.170	4.90	0.100	Ireland	Celtic Sea (FU 20-22)
7.32	0.160	5.49	0.160	UK Scotland	Clyde
7.30	0.160	6.00	0.060	UK Scotland	Clyde (FU13)
8.70	0.060	6.70	0.100	Greece	E.C. Aegean Sea
7.21	0.169	5.77	0.214	Italy	Eastern Ligurian Sea
9.32	0.100	9.03	0.090	Greece	Euboikos Gulf 1
8.27	0.120	7.39	0.140	Greece	Euboikos Gulf 2
8.40	0.060	7.10	0.100	Greece	Euboikos Gulf 3
6.00	0.160	5.60	0.100	Ireland	Irish Sea East (FU 14-15)
8.90	0.110	7.74	0.110	Italy	Ligurian Sea 1
8.32	0.120	6.32	0.150	Italy	Ligurian Sea 2
7.00	0.160	6.00	0.080	Spain	North Galicia (FU25)
7.00	0.160	6.00	0.060	UK Scotland	North Minch (FU 11)
8.15	0.110	7.70	0.140	Italy	Not specified
7.50	0.140	6.00	0.100	Ireland	Porcupine Bank (FU 16)
6.20	0.130	5.30	0.140	Italy	Scilian channel
7.29	0.140	6.49	0.060	Sweeden	Skagerrak
6.00	0.160	5.60	0.080	Ireland	South &SW Ireland (FU 19)
6.60	0.160	5.90	0.060	UK Scotland	South Minch (FU12)
7.00	0.200	6.50	0.065	Portugal	Southwest & South Portugal (FU 28-29)
7.30	0.120	6.60	0.140	Greece	Thracian Sea
8.30	0.110	6.60	0.130	Greece	Toroneos & Siggitikos Gulfs
9.98	0.090	8.78	0.080	Italy	Tyrrhenian Sea 1
8.16	0.130	6.50	0.150	Italy	Tyrrhenian Sea 2
8.60	0.060	6.90	0.090	Greece	West central Aegean Sea
8.00	0.150	6.50	0.080	Spain	West Galicia & North Portugal (FU26-27)

Table 2. Size at first maturity in females and CV obtained by year and with pooled data (2009-2013 and 2016). Months, range of CL and the number of individual used in the analysis, and the parameters of the fit are also shown.

Year	**Months**	**Range Max-Min CL (mm)**	**N**	**a**	**b**	**CL_{50} (mm)**	**CV**
	Mature females: stages II, III, IV, V, ovigerours						
2009	May, Jun, Jul, Ago	24-45	184	-11.4887	0.4522	25.4	0.048
2010	Apr,May, Jun, Jul, ago, Sep	18-58	334	-35.4533	1.3128	27.0	0.008
2011	Apr,May, Jun, Jul, ago, Sep	21-38	355	-31.4582	1.2528	24.9	0.010
2012	May, Jun	22-42	94	-524.951	10.8565	26.5	>2.108
2013	Jun	22-38	79	-26.5815	0.9775	27.3	0.028
2016	Apr, Sep	22-40	168	-11.1671	0.4452	24.9	0.027
Pooled data	Apr, May, Jun, Jul, Ago, Sep	18-58	1213	-17.1272	0.6696	25.6	0.007
	Mature females: stages III, IV, V, ovigerours						
2009	May, Jun, Jul, Ago	24-45	184	-5.7052	0.2165	26.2	0.074
2010	Apr,May, Jun, Jul, ago, Sep	18-58	334	-13.564	0.4636	29.2	0.011
2011	Apr,May, Jun, Jul, ago, Sep	21-38	355	-10.9885	0.3896	28.1	0.011
2012	May, Jun	22-42	94	-10.3855	0.3287	31.5	0.028
2013	Jun	22-38	79	-37.1415	1.278	28.9	0.013
2016	Apr, Sep	22-40	168	-7.2469	0.2469	29.3	0.025
Pooled data	Apr, May, Jun, Jul, Ago, Sep	18-58	1213	-9.6642	0.3372	28.6	0.007

Table 3. Length-Weight relationship for both sexes for year and for the pooled data (2009-2013 and 2016). The range of the CL and the number of individual used in the analysis and CV of the parameter b are shown.

Year	N	Range max-min (mm)	Sex	a	b	CV
2009	173	25-49	M	0.000454	3.111669	0.027
	182	24-45	F	0.002264	2.647029	0.044
2010	84	10-40	M	0.000558	3.064309	0.033
	80	20-37	F	0.000699	3.028037	0.028
2011	237	22-55	M	0.00105	3.903621	0.027
	263	13-42	F	0.000998	2.925653	0.017
2012	48	24-42	M	0.002528	2.637364	0.094
	57	22-42	F	0.000758	2.977849	0.026
2013	31	25-36	M	0.000112	3.516205	0.07
	43	22-38	F	0.002153	2.664498	0.053
2016	129	21-43	M	0.001246	2.851696	0.032
	141	21-40	F	0.00067	2.028426	0.036
All years pooled	702	10-55	M	0.000845	2.953452	0.017
	766	13-45	F	0.001873	2.726119	0.022

Table 4. Asymptotic length and K parameter by sex derived from empirical relationships based on Pauly (1984) and Pauly et al. (1996), respectively.

Males		**Females**	
CL_{max}	CL_{∞}	CL_{max}	CL_{∞}
63 mm	66mm	58 mm	61 mm
K	K	K	K
0.184	0.167	0.130	0.122

Table 5. Biological parameters proposed for *Nephrops* in FU 30 (Gulf of Cadiz).

FU 30	Males	Females
Size at first maturity	30 mm	25.6 mm
Growth-K	0.167	0.122
Growth-L_{∞}	66 mm	61 mm
Length-Weight-a	0.000845	0.001873
Length-Weight-b	2.953452	2.726119

Figure 1. Proportion of mature females by carapace length using Criterion 1 and Criterion 2 for the pooled data (2009-2013 and 2016) and maturity oogive.

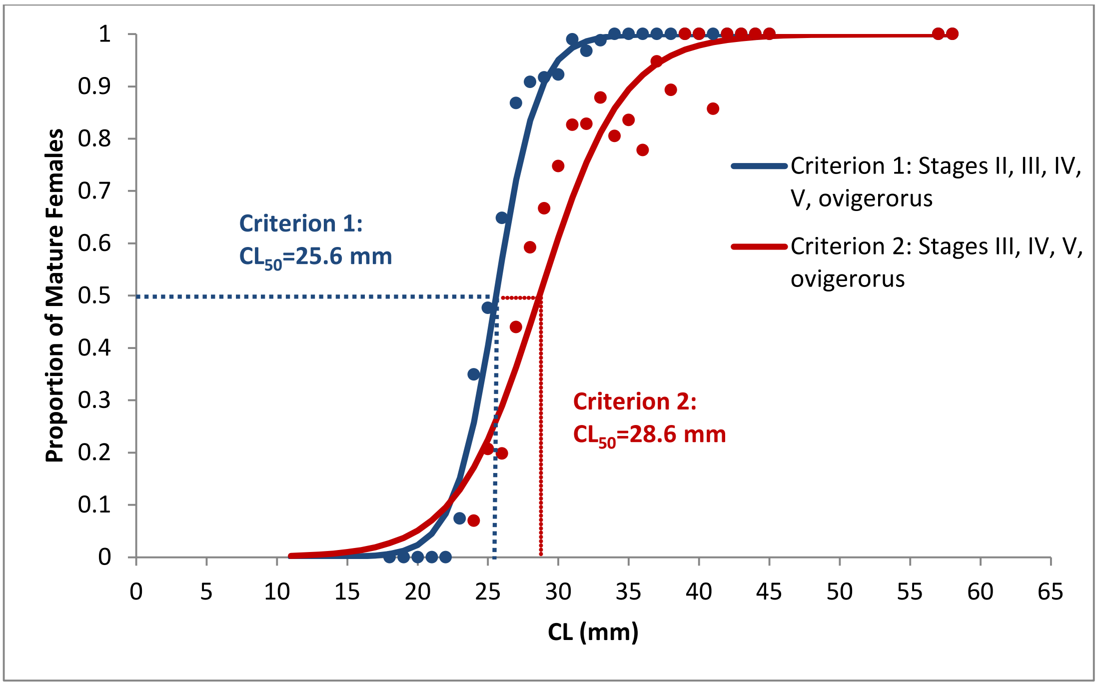


Figure 2. Appendage masculina lenght and CL relationship for the 2009-2016 period (except 2011) and for pooled data. Segmented regression lines, breakpoints estimates and standard error (within brackets) are shown.

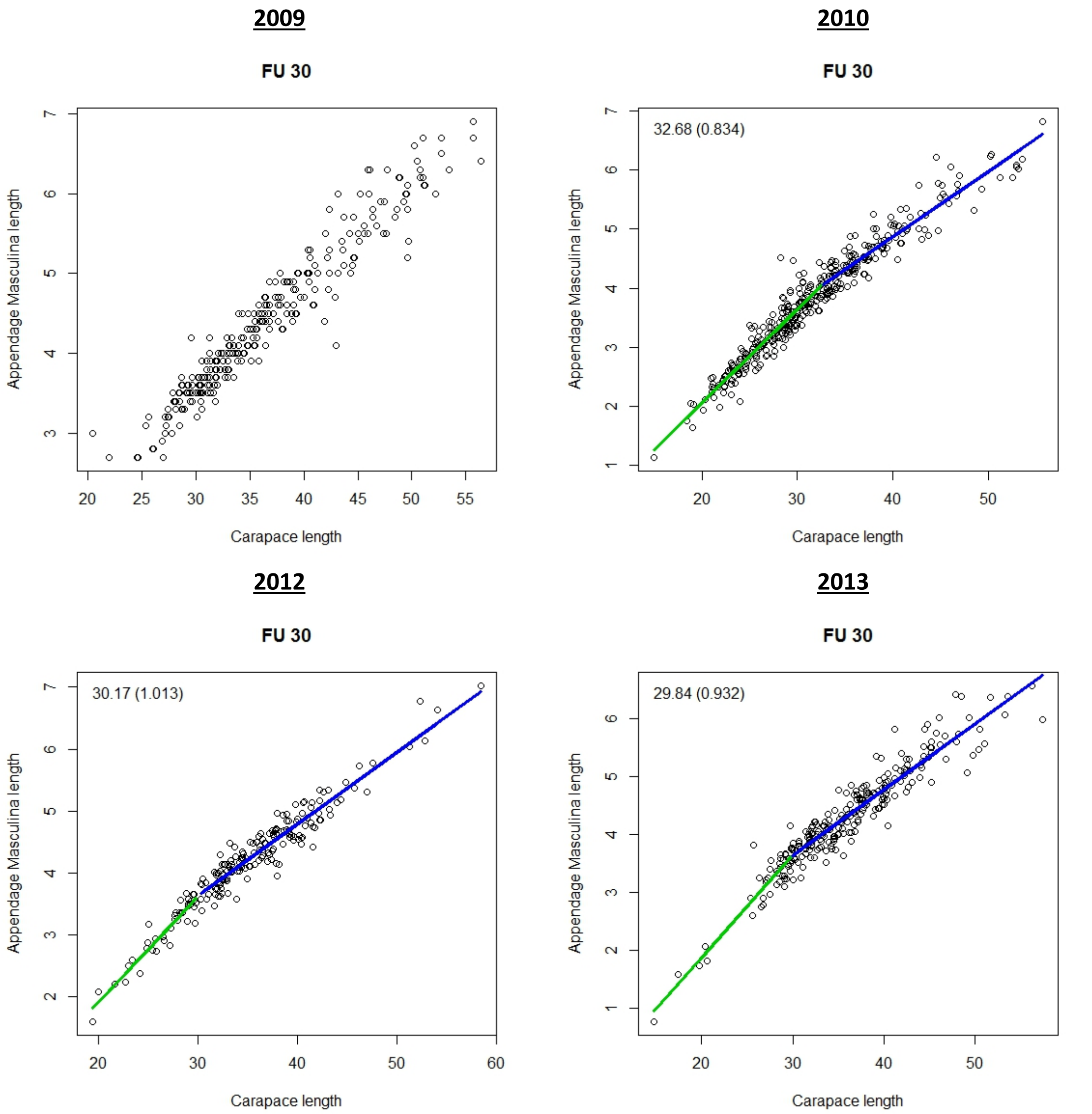
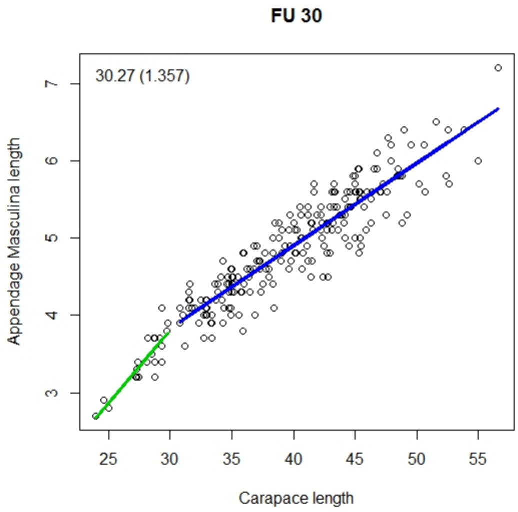
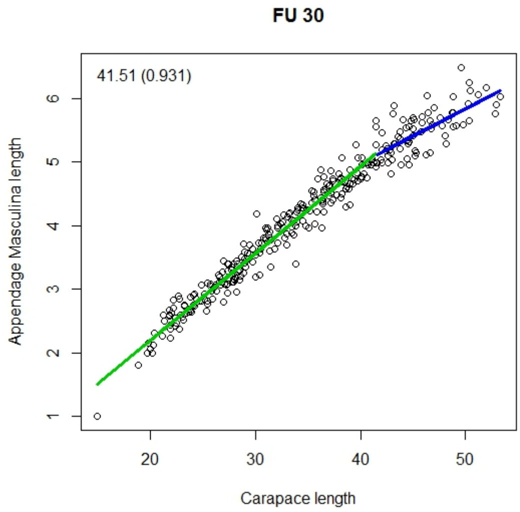


Figure 2. **Cont.** Appendage masculina lenght and CL relationship for the 2009-2016 period (except 2011) and for pooled data. Segmented regression lines, breakpoints estimates and standard error (within brackets) are shown.

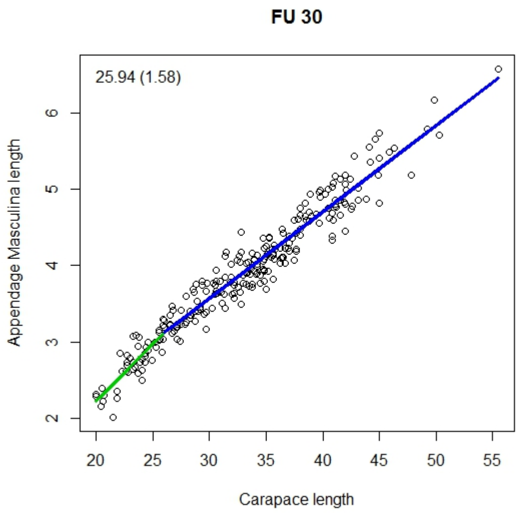
<u>2014</u>



<u>2015</u>



<u>2016</u>



<u>All year pooled</u>

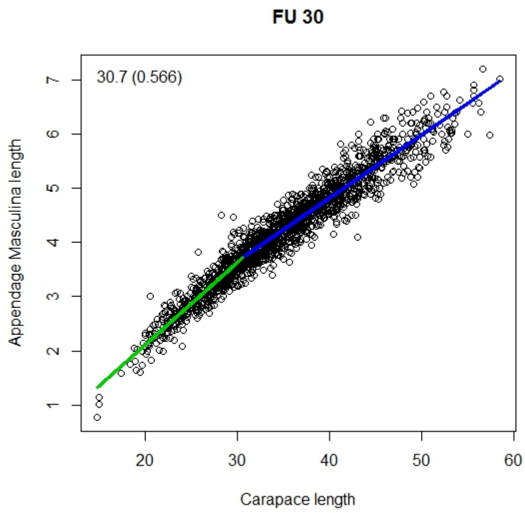


Figure 3. Length-Weight relationship in both sex for for pooled data (2009-2013 and 2016).

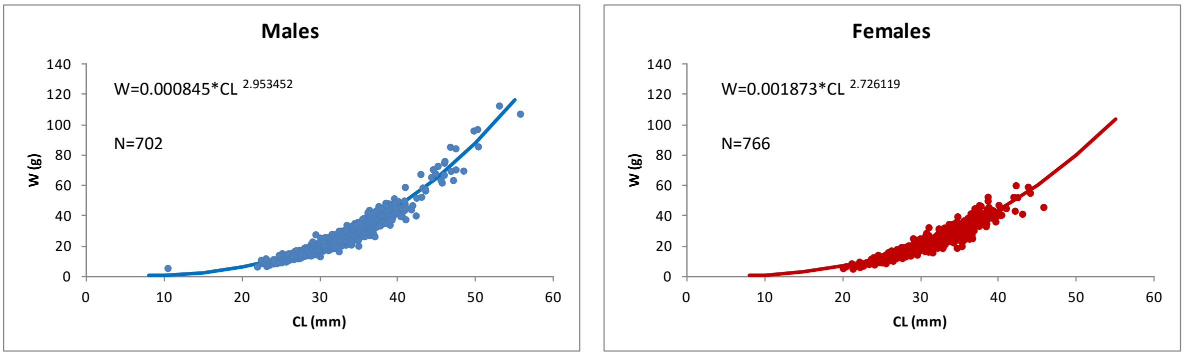
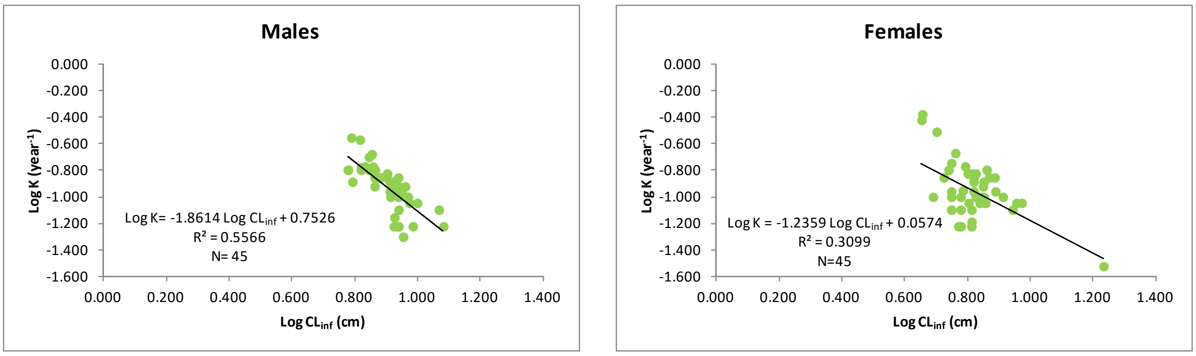


Figure 4. *Nephrops* auximetric graph for males and females.



Nephrops (FU 30) UWTV Survey on the Gulf of Cadiz Grounds

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INTRODUCTION

Underwater television surveys to monitor the abundance of *Nephrops* populations were pioneered in Scotland in early 90's. The estimation of Norway lobster abundances using UWTV systems involves identification and quantification of burrow density over the known area of *Nephrops* distribution. This can be used to produce a raised abundance estimate for the stock. In last decade, this technique has received detailed attention in a series of ICES workshops aimed at standardising methodologies and quantifying the uncertainties associated with the method (ICES, 2007; ICES, 2008; Campbell et al., 2008). A direct approach of using the UWTV surveys as the basis for catch advice by applying harvest ratios (HRs) was proposed in 2007 (Dobby at al., 2007; ICES, 2007). Currently, ICES considers this methodology as the most appropriate, and suggests that, the so-called UWTV surveys can be used in order to obtain an absolute estimate of the biomass of Norway lobster and it can be use as the basis of the scientific advice according WKNEPH 2009 (ICES, 2009). Thus, UWTV surveys have been extended to many stocks in Atlantic waters and Mediterranean Sea resulting in about 18 stocks prospected with these surveys in 2014.

Beside, these UWTV surveys are an excellent platform for obtain information on the benthic habitats and the monitoring of benthic macro fauna of the sedimentary areas in the circa littoral zone deep, such as the communities of pennatulaceans mega fauna and the burrowers fauna that have been included in the OSPAR List (OSPAR, 2010), on the impact of fishing activity on the bottom, as well as information of environmental variables. This information could be useful in the monitoring programs within the Marine Strategy Framework Directive.

At the moment, the ICES advice for the *Nephrops* stock in the Gulf of Cadiz (FU 30) is on the basis of a data-limited approach, meaning that no analytical stock assessment is conducted in this FU. According to this approach, FU 30 is considered as category 3.2.0 (ICES, 2012a) and it is assessed mainly by the analysis of the LPUE series trend. Thus, the catch recommendation is set at a long-term average, with and "uncertainty cap" or "change limit" of ± 20% comparing with recent catches. However, some circumstances that have happened in the fishery since 2012 might increase the uncertainty associated to the commercial LPUE index: low TAC in FU30 during the last years, the special situation after the penalty in 2012 with a reduction of the TAC for 3 years and the assignment of *Nephrops* quotas by vessel implemented in 2014 that might have caused unreported landings.

The Spanish Oceanographic Institute (IEO) carried out an exploratory *Nephrops* UWTV survey on the Gulf of Cadiz fishing grounds in 2014 within the framework of a project supported by Biodiversity Foundation (Spanish Ministry of Agriculture, Food and Environment) and European

Fisheries Funds (EFF). Nowadays, IEO is carried out yearly UWTV survey in the Gulf of Cadiz (FU 30) since 2015. The aim in this WKNEP 2016 is to validate the UWTV survey and to define the reference points in order to give a scientific advice according WKNEPH 2009. In this working document a description of the UWTV surveys in the Gulf of Cadiz is carried out.

DISTRIBUTION OF *NEPHROPS* IN THE GULF OF CADIZ (FU 30)

The boundary used to delineate the limits of the *Nephrops* ground was based mainly on the VMS data of fishing activity in the years 2012 and 2013. Additionally, other sources of information have helped to know the *Nephrops* distribution area in the Gulf of Cadiz such as, the bottom trawl surveys (1993-2015 time series) and the bathymetric and sedimentary information obtained from the LIFE-INDEMARES/CHICA project (www.indemares.es) and from the first ISUNEPCA UWTV survey carried out in 2014, respectively.

The VMS positional data were selected from fishing vessels targeting *Nephrops* using the logbooks. Geographical positions are available at least every two hours and the speed when the vessels are fishing ranges between 3 and 4 knots but speeds up to 5 knots can be achieved according to the knowledge from onboard fisheries observers. Therefore, speed values lower 5 knots were selected for the analysis. Records at entries and exits from main ports and from distances to the coast lower 6 mn, where is forbidden trawling, were removed. Additionally, records allocated lower 200 m isobath were removed too since *Nephrops* catches were near zero.

After those different filters were applied, the locations resulting were associated to the logbook information. Since the catches by vessel are daily aggregated, *Nephrops* catches were spread in a proportional way to the number of points that this vessel had in the day.

For the spatial distribution of the fishing effort and the catches associated, the working area was divided in square of 0.5 mn of side, and the mean distance of separation between two consecutive locations. An interval of mean time between 15 and 20 minutes and a mean speed of 3 knots were used. Spatial analysis tools were used to group the point by square, joined the *Nephrops* catches and counting the number of points.

Figure 1 shows the fishing activity targeting *Nephrops* base on VMS analysis and the *Nephrops* abundance obtained in the bottom trawl survey series (1993-2014) in the Gulf of Cadiz. This trawl surveys are framed in the Working Group of the International Bottom Trawl Surveys, IBTS). The IBTS in the Gulf of Cadiz are yearly carried out in March and November and they are targeting to demersal species following a random stratified sampling design with 5 strata (30-50 m, 51-100 m, 101-200 m, 201-500 m and 501-700 m). *Nephrops* is only distributed in two deepest strata. The sampling design in the IBTS survey carried out in the Gulf of Cadiz in 2015 is showed in the Figure 2.

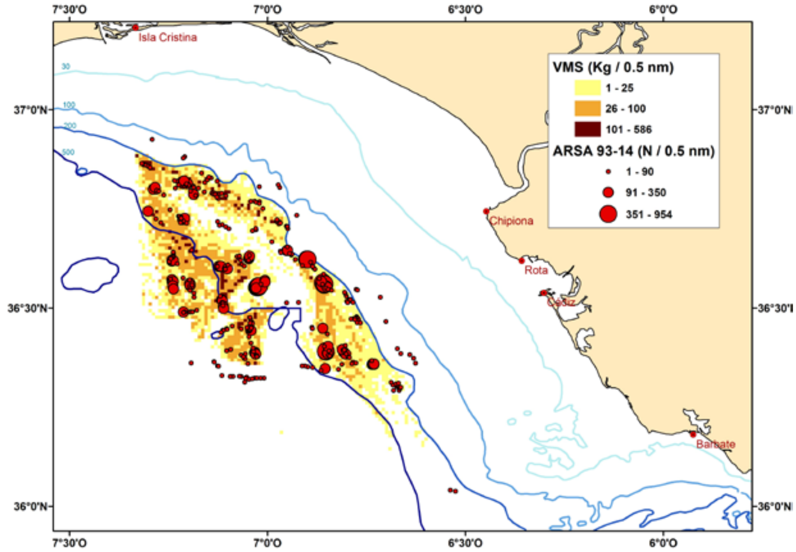


Figure 1. Results of the VMS analysis (2012-2013) and the *Nephrops* abundance obtained from the bottom trawl surveys (IBTS) series (1993-2014) carried in the Gulf of Cadiz.

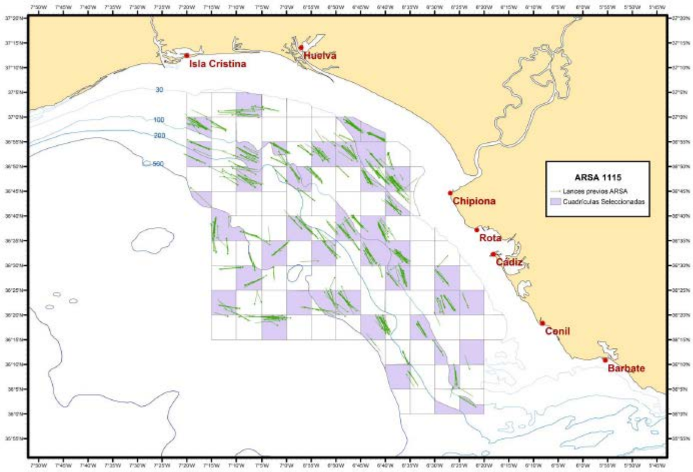
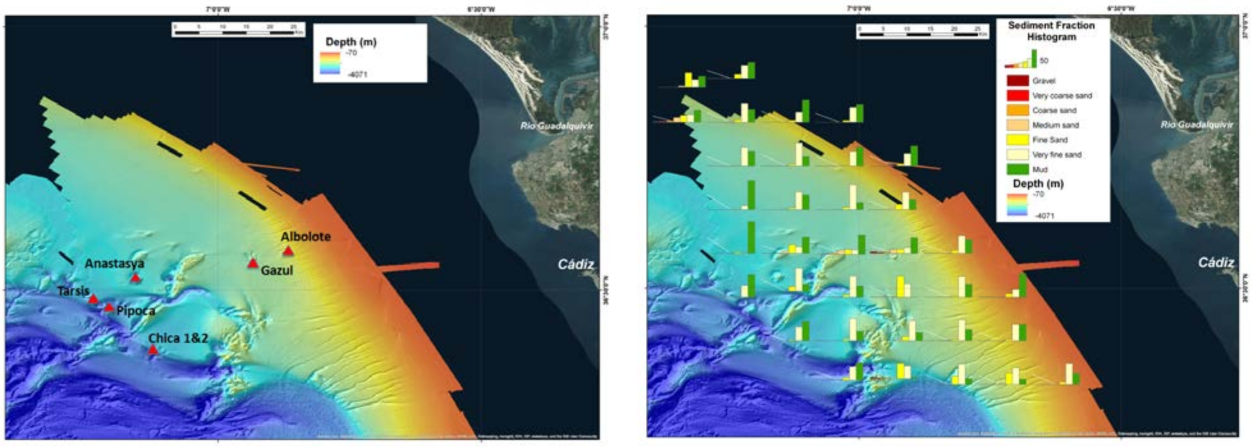


Figure 2. Random stratified sampling desing in the bottom trawl survey carried out in November 2015 in the Gulf of Cadiz. Blue squares are the selected square for this survey and green lines correspond to the hauls carried out in these squares in the historical time series.

The *Nephrops* distribution observed from the bottom trawl surveys is in concordance with the spatial distribution of the fishing activity on the ground in the Gulf of Cadiz (200-600 m depth). Nevertheless, small quantities of *Nephrops* occur below 200 m isobaths and on the deepest area (about 600-700 m) although none bottom trawl fleet activity targeting to *Nephrops* is observed in the VMS. The particular bathymetry on this area shows deep channels with strong currents in the border deepest that prevent the fishing activity (Figura 3a). However, beyond this channel the composition of the substratum could be suitable for *Nephrops* constructs their burrows although maybe for the fleet it is a far away zone and it might not be profitable regarding to benefits since the *Nephrops* abundance seem low, according to trawl surveys information.

In the Gulf of Cadiz there are some mud volcanoes which could have a negative influence about *Nephrops* distribution and the fishing activity (Figure 3a). The spatial distribution of the size grain in the sediment obtained in the 2014 ISUNEPCA UWTV survey shows sediments more classified near of these volcanoes (Figure 3b). For example, near to Gazul volcano can be observed hard substratum with sponges and corals. Other zones where *Nephrops* fishing activity is absent correspond to bottom with a high percentage of sand (Figure 3b). These types of sea bed are not appropriated for *Nephrops* since this species needs bottoms of muddy nature to be able to construct their burrows.



a) b)

Figure 3. Bathymetry of the Gulf of Cadiz. a) Mud volcanoes and b) spatial distribution of the grain size obtained from samples taken during the ISUNEPCA UWTV survey in 2014. (Source: bathymetry from INDEMARES_Chica project)

DESCRIPTION OF THE UWTV SURVEYS

Vessels and dates

The UWTV surveys carried out in the Gulf of Cadiz were namely with the acronym ISUNEPCA. Table 1 shows the vessel and dates for each survey:

Year	Vessel	LOA (m)	Tonnage (GT)	Power (Kw)	Dates (day/month)
2014	B/O Ángeles Alvariño				22/08-02/10
2015	B/O Ramón Margalef	46.70	951	900	04-13/06
2016	B/O Ángeles Alvariño				06-16/06

Survey Design

The surveys were designed from a multidisciplinary approach although some specific objectives have been changing in the survey series. The objectives are listed below:

1. To set up the equipment and the UWTV survey methodology in the Gulf of Cadiz (in 2014 and 2015)

2. To obtain estimates of *Nephrops* burrows densities from a randomized isometric grid of UWTV stations
3. To delimit the boundaries of *Nephrops* in FU 30
4. To obtain density estimates of macro benthos species and the occurrence of trawl marks on the sea bed
5. To collect sediment samples using a meso Box-Corer (in 2014)
6. To collect oceanographic data using a sledge mounted CTD
7. Sea bed morphological and backscatter analyses (in 2016)

This working document is only focus to the estimation of *Nephrops* abundance using UWTV systems.

In 2014, a grid of 35 stations with spacing between them of 5 mn was planned (Figure 4a). Additionally, 7 stations located on the shallower edge of the study area were considered as reserve in order to confirm the boundaries of the *Nephrops* distribution. The stations ranged from 130-640 m depth with an average depth around 410 m, covering an area of 2896 Km^2.

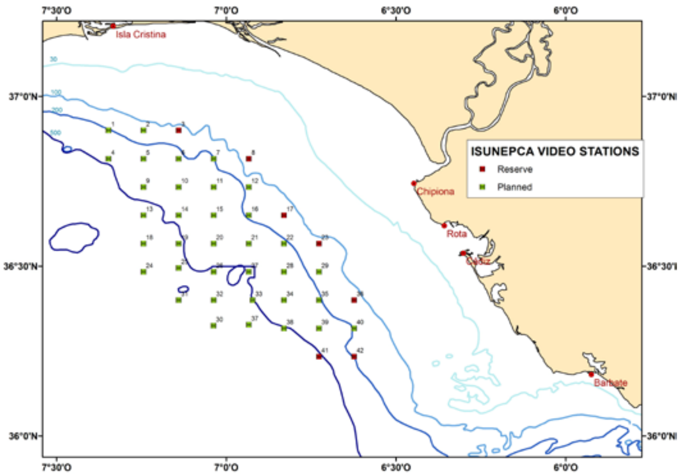
In 2015 and 2016, the space between stations was reduced to 4 mn and the area was increased resulting in a higher number of stations in relation to the exploratory survey carried out in 2014 (Figure 4b and 4c). The grid in 2015 was square while in 2016 was rhomboid but a similar number of stations were planned in both years (60 in 2015 and 62 in 2016). Regarding to the number of stations considered as reserve, it was increased in 2016 (3 in 2015 and 14 in 2016). The stations ranged from 90-650 m depth with an average depth around 350 m covering an area of 3000 Km^2, in 2015 and 2016.

Equipment and operational protocol

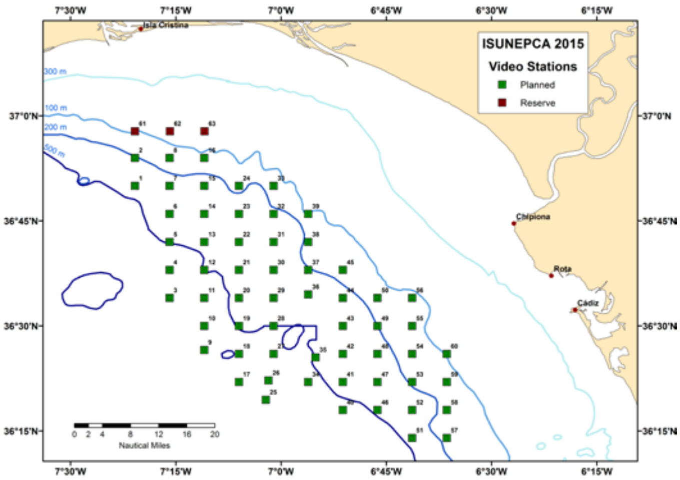
The sledge and the main equipment were developed and made by a small company, based in the design of Shand and Priestley (1999) (Figure 5). The UWTV equipment is composed of:

- *Structure:* Tubular structure in inox (AISI 316)
- *Image system:* 2 FullHD (1080x1920 pixels) video cameras which are placed in 2 reduced size CPUs with a processor of 700 MHz, 512 Mb RAM and 16 Gb for the storage memory. The cameras have an angle of inclination of 45° in relation to the ground.
- *Lighting system:* 1 high power LED made according to the model of this company
- *Lasers system*: 2 lasers of 200 mW spaced 75 cm.
- *Navigation system*: accelerometer and magnetometer both tri-axial with internal data processor, offering offset data of heading, pitch and roll with precision of 1º
- *Communication system:* 1 multiplexor and an IBERCISA MCS-E/30/1500-11 (1500 m and 11 mm diameter coaxial cable)
- *Auxiliary system*: 1 high capacity lithium battery
- *Deck system*: a control unit

2014



2015



2016

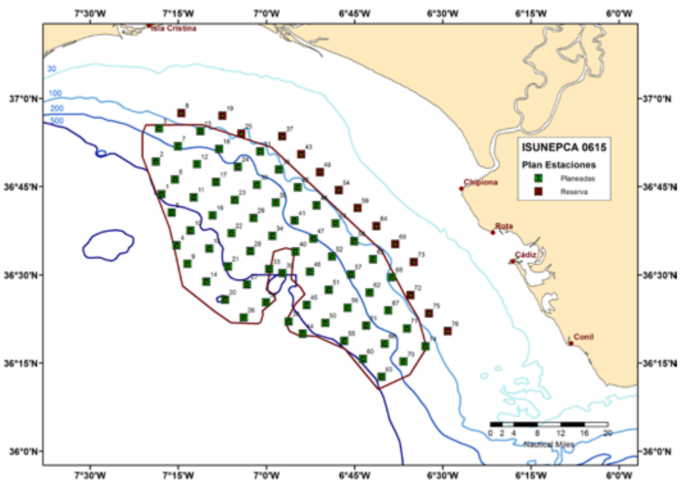


Figure 4. Stations grid planned in ISUNEPCA UWTV survey in 2014-2016 period.

Figure 5. Sledge used in the ISUNEPCA UWTV surveys

The sledge is deployed and towed at the side of the vessel using an 11 mm diameter coaxial cable. This option results in a continuous and without jumpy displacement of the sledge. Once the sledge is stable on the seabed it is towed at between 0.5-0.6 knots in order to obtain the best possible conditions for counting burrows and 10 good minutes are recorded. This time corresponds to 160 m swept, approximately. Although SGNEPS recommended that verification recounts should be 7 minutes (ICES, 2009b) this was increased to 10 minutes for the Gulf of Cadiz. This was because at the lower densities observed the relative scale of variation between minutes was relatively higher than typical in other areas. The footages were recorded onto internal memory of the image system and were downloaded after each station onto the computer.

Vessel position (DGPS) is logged to text file via Hyperterminal and a HiPAP transponder on the sledge is used to obtain the sledge position. The distance over ground estimate (DOG) is calculated using the sledge position and the field of view of the video footages is 75 cm (FOV), which is confirmed using lasers.

Counting protocol

According to the SGNEPS recommendations all scientists must be trained and familiarized with the identification of *Nephrops* burrows (ICES, 2008) before the survey. Training material and validated reference footages are used for this propose. Porcupine Bank reference footage is used because the absence of specific reference footage in the Gulf of Cadiz. In the next WGNEPS (November 2016), reference footage from the Gulf of Cadiz (FU 30) will be created.

Linn's concordance correlation coefficient (CCC) (Linn, 1989) is used to analyze the individual's counting against the reference counts. SGNEPS (ICES, 2009b) suggests that individual's counts should be higher 0.8 but a lower threshold might be considered acceptable establishing a CCC value limit of 0.5. In these surveys a threshold ≥ 0.5 was accepted for considering a reader as valid (Figure 6). The number of *Nephrops* burrows systems (multiple burrows in close proximity which appear to be part of a single complex are only counted once) and *Nephrops* in and out of burrows are counted for each one-minute interval according to WKNEPHBID (ICES, 2008). Visibility is subjectively classified using the follow classification key: excellent, good, ok, acceptable, poor and nil. Ground type and speed of the sledge are recorded too according to the standard classification keys. All recounts are conducted by at least two trained "burrow identifying" scientists independent of each other. In 2014, recounts were done in the lab after the survey while in 2015 and 2016, a high percentage of the recounts were conducted on board the research vessel during the survey.

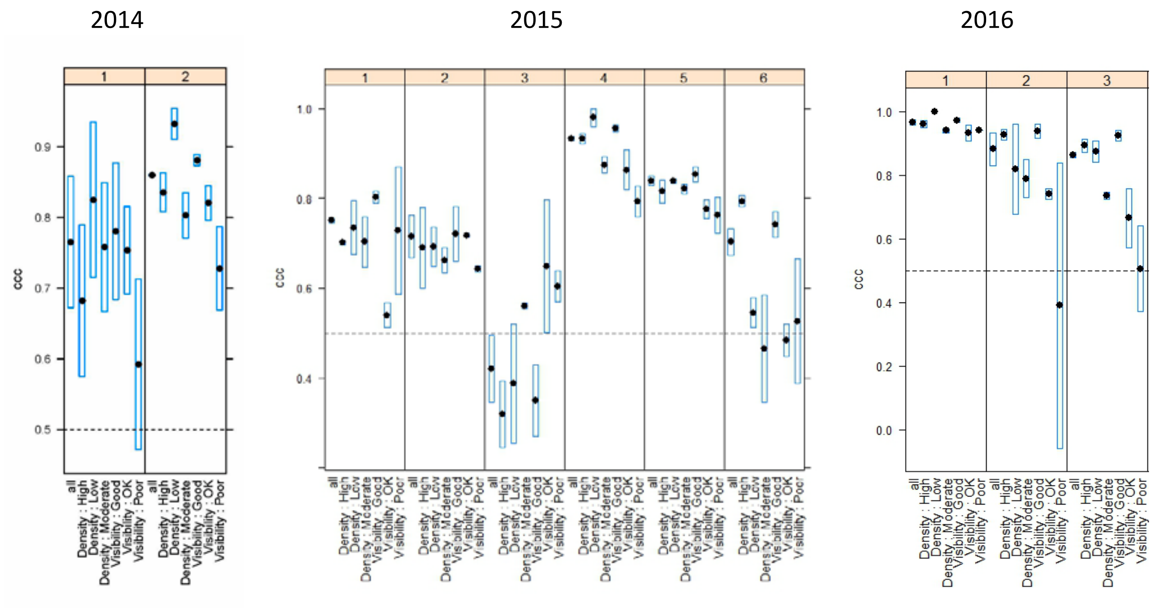


Figure 6. Linn's concordance correlation coefficient (CCC) obtained in 2014-2016 period.

Abundance estimation

Estimates of density at each station are calculated from standardized *Nephrops* burrows recounts divided by the area observed. This area is calculated multiplying the DOG by the FOV (Figure 7). All recounts are carried out on the footage with a FOV of 75 cm. This assumes that the sledge was flat on the seabed (i.e. no sinking). Then, mean *Nephrops* burrows density is raised to the total area surveyed (swept area method) following the next equation:

$$\frac{\sum N^{o}\, burrows/swept\ area}{N^{o}\, stations} * total\ area$$

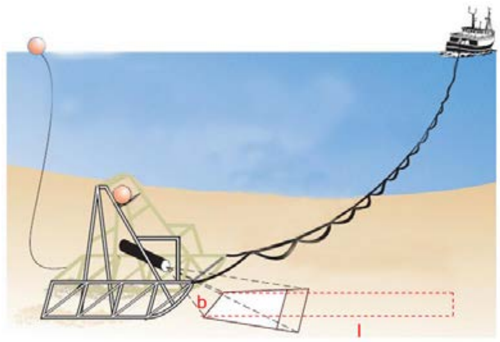


Figure 7. Sledge design showing field of view (b) and distance of TV track (l) with floatation and angled camera set-up

In addition, a geostatistic analysis is carried out applying an ordinary kriging using ArcGIS software. The result of kriging is used to obtain a second *Nephrops* burrows abundance estimate, dividing the area in polygons with the some density range and raising this density to the surface of the each polygon. The summary of the method used in the geostatistic analysis for 2014-2016 period is shown in Table 2. The resulting blanked grid is used to estimate the domain area and total burrow abundance estimate. Krigged estimation variance or CV is carried out using the EVA: Estimation VAriance software (Petitgas and Lafont, 1997).

Table 2. Summary of the geostatistic method.

	2014	**2015**	**2016**
Method	Kriging	Kriging	Kriging
Type	Stable	Ordinary	Ordinary
Variogram	Semivariogram	Semivariogram	Semivariogram
Number of lags	6	12	12
Lag size	0.066667	0.066667	0.066667
Nugget	0.000544	0.002927	0.001457
Range	0.420001	0.263249	0.138686
Anisotropy	Si	No	No
Partial sill	0.007347	0.003993	0.005588

Sources of bias

A number of factors are suspected to contribute bias to UWTV surveys (ICES, 2007). In order to use the survey abundance estimate as absolute it is necessary to correct for these potential biases. The main bias is the “edge effect” which is a moderate source of overestimation when deriving *Nephrops population* size from underwater TV surveys. This bias is related to the counting of burrow complexes which lie mainly outside the viewed track. The field of view of the camera is 0.75 cm and the expert judgment of the mean burrow diameter is 27 cm. The estimated edge effect bias using the simulation approach suggested by Campbell et al., (2009) is established in 1.24. Other bias identifies are the “burrow detection” and “burrow identification regarding to visibility quality and the presence of other burrowing macro benthic species. The burrow detection rates were thought to be relatively high due to good water clarity. Burrow identification could be overestimated since some squat lobsters were observed at burrow entrances. Regarding to the “occupancy”, is assumed that 100% of burrows are occupied for an individual of *Nephrops*. The proposed cumulative correction factor for the Gulf of Cadiz was 1.28 (Table 3).

Table 3. The bias associated with the estimates of *Nephrops* abundance in the Gulf of Cadiz (FU 30).

	Edge efect	**Detection rate**	**Species identification**	**Occupancy**	**Cumulative bias**
FU30: Gulf of Cadiz	1.24	0.90	1.15	1	1.28

RESULTS

All planned UWTV stations were completed in each ISUNEPCA UWTV survey carried out in 2014, 2015 and 2016. However, the stations considered as reserve (in order to confirm the *Nephrops* limits) could not be carried out in the time window of the survey in 2014 and only in a low percentage in 2016 (Table 4). The reserve stations were always null because the visibility was poor or nil. These stations are allocated in depths ranging about 80-120 m where the clarity of the water is low and where the presence of other burrowing fauna could affect in the *Nephrops* identification. Nevertheless, the *Nephrops* abundance in this depth could be probably low according to the information of VMS and bottom trawl surveys.

In general, the water visibility in the Gulf of Cadiz since 250 m of depth approximately is good and it is increasing with the depth up to excellent clarity. However, some of the planned stations were visited again because the visibility was bad. The mainly reason was the fishing activity which cause considerable amounts of suspended material in the water near the seabed making difficult the identification of *Nephrops* burrows. These stations were revisit during the weekend when the fleet is docked in accordance with the regulation. Other reasons were the resuspended sediment when the current on the seabed is strong and travels in the same direction to the sledge or the presence of high abundance of euphausiaceos (krill) that prevent the vision in front of the sledge. In all these cases, the stations were revisit obtaining valid footages in the most of the stations.

Table 4. Stations used in the estimation of *Nephrops* abundance. Planned, considered as reserve and null stations are shown.

Nº stations	**2014**	**2015**	**2016**
Planned	35	60	62
Reserve planned/done	7/0	3/3	14/3
Valid	**31**	**58**	**58**
Null	3	5	4

Table 5 shows the summary of the univariate statistics and geostatistic analysis for the burrow density estimates adjusted for the cumulative bias and the density estimates obtained using the swept area method on ISUNEPCA UWTV surveys in the Gulf of Cadiz (2014-2016). For 2014, data are not adjusted.

The mean burrow density in 2014 was 0.101 burrows/m^2 with a range of observations from 0.00 and 0.3 burrows/m^2. The mean burrow density observed in 2015, adjusted for the cumulative bias, was 0.097 burrows/m^2 while a lower mean burrow density was observed in 2016 (0.075 burrows/m^2). In general, the range of the observations was relatively high in both years (0.00-0.345 burrows/m^2 in 2015 and 0.00-0.328 burrows/m^2) showing a similar range that in *Nephrops* FU 16 (Porcupine Bank) (Doyle et al., 2014).

The final modeled density surfaces in 2014, 2015 and 2016 are shown as a heat maps and bubble plots in Figure 8. The spatial pattern of burrow density is not consistent in the years but some reasons could explain this fact.

ISUNEPCA 2014 was the first *Nephrops* UWTV survey in the Gulf of Cadiz and it must be considered as an exploratory survey. This survey offered the opportunity to set up the equipment and the methodology in this area. In addition, it was an important training both for the scientists and the crew of the vessel. Thus, scientists were able to get to know the survey protocol, the use of the UWTV equipment and *Nephrops* burrow identification.

Table 5. Summary of univariate statistics and geostatistic analysis for the burrow density estimates on ISUNEPCA UWTV survey in the Gulf of Cadiz for 2015 and 2016. For UWTV survey in 2014 only the univariate statistics are shown. The mean burrow density and burrow density estimates through Swept Area Method is also shown.

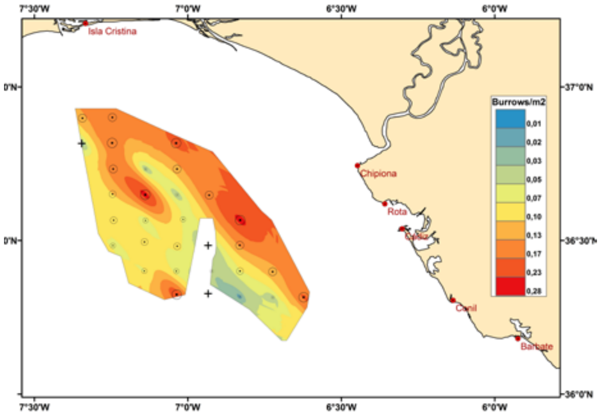
	2014*	**2015**	**2016**
Univariate Statistics			
Samples	31	58	58
Min	0	0	0
Max	0.3	0.345	0.328
Mean	0.101	0.097	0.075
Standard deviation	0.083	0.081	0.083
Skewness	0.746	0.956	1.527
Kurtosis	2.747	3.511	4.697
1-st Quartile	0.032	0.021	0.017
Median	0.080	0.079	0.039
3-rd Quartile	0.167	0.134	0.096
Geostatistic Analysis			
Prediction Summary			
Min	0.0418	0.0198	0.0174
Max	0.1526	0.1676	0.1815
Mean	0.0987	0.0905	0.0776
Variance	0.0008	0.0017	0.0018
Prediction Errors			
Mean	-0.003235	0.000047	0.000374
Root-Mean-Square	0.081749	0.073483	0.081045
Mean Standardized	-0.032525	-0.002570	0.006325
Root-Mean-Square Standardized	0.999095	1.028630	1.020033
Average Standard	0.081634	0.071561	0.079299
Domain area (Km^2)	**2896**	**3000**	**3000**
Min abundance estimate (millions)		278.7	207.9
Max abundance estimate (millions)		317.4	257.9
Mean abundance estimate (millions)	282.0	**298.1**	**232.9**
CV (%)		7.60	7.26
Swept Area Method			
Mean density (Burrows/m^2)	0.101	0.090	0.075
Total burrows (Millions)	294.7	271.3	225.3

*Data in 2014 are not adjusted

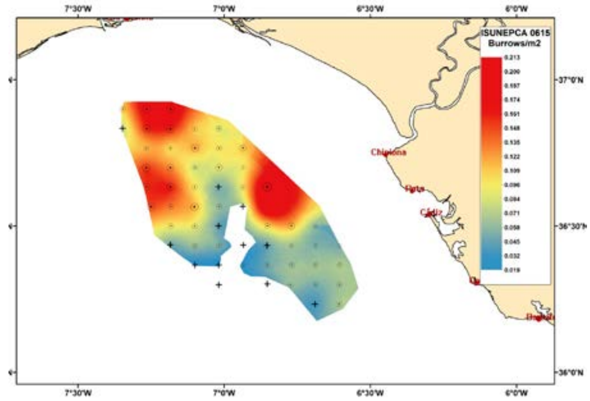
The spatial co-variance and other spatial structuring geostatistical analysis were conducted but some difficulties were identified as the low number of observations mainly in the shallower border and no observations with zero densities on the boundary ground. A number of assumptions were considered and explored. The *Nephrops* density in the shallower border of the area was relatively high in 2014 but it was not possible to add UWTV stations in an adaptive way in order to ensure the boundaries of the ground in this first survey.

On the other hand, differences between the two counters were found in footages in bad conditions of visibility, with small *Nephrops* burrows and with high density of other burrowing species. These footages mainly correspond to the stations in the shallower border of the area. Moreover, all recounts were carried out in the lab after de survey and during a wide period, which could influence in the *Nephrops* quantification. In addition, the *Nephrops* delimited area used in the analysis was lower than in further surveys and probably did not cover the whole of the *Nephrops* distribution.

2014



2015



2016

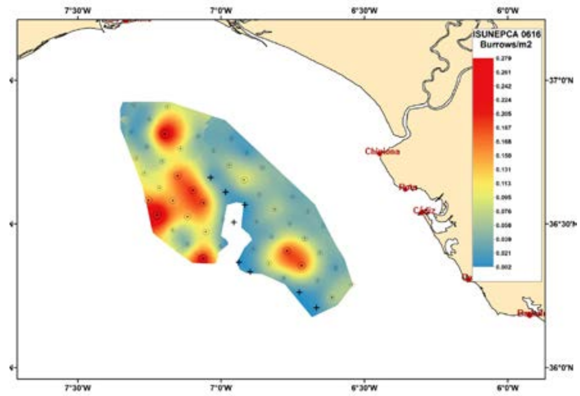


Figure 8. ISUNEPCA UWTV bubble plot of the burrow density observations overlaid on a head map of the krigged burrow density surface for 2014, 2015 and 2016. Station positions with zero density are indicated using a +.

In ISUNEPCA UWTV survey carried out in 2015, the number of stations and the space between them was increased. However, the border was also under sampled mainly in the shallower limit. In addition, an overestimation of the number of burrows may have happened. Many participants in the survey were not experienced in the quantification of *Nephrops* burrows. These facts can influence in the geostatistic analysis. For example, the nucleus with high burrow density allocated in front of the mouth of the Guadalquivir River, only a unique station with very high numbers of *Nephrops* burrows looks give in this area too much weight in the analysis.

The geostatistic *Nephrops* abundance estimate obtained in 2016 is 233 millions of individuals (225 millions of individuals through the Swept Area Method) lower than 2015 (Table 5). Unlike the previous year, the stations covered better the area, with more stations in the border in 2016. Moreover, the identification of the *Nephrops* burrows was carried out for three scientist who participated in the two previously surveys and therefore with more experience. A more realistic result was obtained in ISUNEPCA 2016 according to the VMS information.

The *Nephrops* abundance estimate obtained in the bottom trawl survey (IBTS-surveys) carried out in the Gulf of Cadiz in March 2016 increased in relation to the previous year (ICES, 2016). So, we can think that the reduction of the *Nephrops* abundance from UWTV survey in 2016 could be caused for a under sampling of the border area together with an overestimation of the number of burrows but not due to decreasing of the *Nephrops* abundance in FU 30.

CONCLUSIONS

1. The equipment has been tested and the methodology of the UWTV surveys has been set up in the Gulf of Cadiz
2. VMS, bottom trawl survey, bathymetric and sedimentary structure information give a valuable knowledge about the boundaries of the *Nephrops* distribution in the Gulf of Cadiz
3. The ISUNEPCA UWTV survey in 2014 should be considered as exploratory.
4. The abundance estimate in 2015 should be reviewed and only the estimate obtained in 2016 should be used in this benchmark.
5. ISUNEPCA UWTV survey can be used as a basis on the scientific advice.

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Annex 3: Recommendations

Recommendation	Adressed to
(not a recommendation, just a note for the report) there is some linguistic uncertainty in the term for Harvest Ratio from UWTV survey-based assessment.	
Create a new EG on reference points that will examine the methodology for all *Nephrops* reference points with a focus on M and growth. Potential project too.	
Further explore other information (e.g. Pandalus survey, cpue data) that could be used in a category 3 assessment for FU32. Recipient: ToR for the next WKNep.	
Explore the possibility of a one-off UWTV survey for FU32 assessment.	ACOM (Norway)
Random on-board sampling programmes are directed to mixed demersal fisheries do not necessarily give adequate coverage of *Nephrops* fisheries. *Nephrops* fisheries could be a separate métier for improved use in the assessment, or simply increase sampling levels in the existing program. Recipient: Joint SCICOM-ACOM Steering Group on Integrated Ecosystem Observation and Monitoring.	SSGIEOM
FU29 and 30. Political split vs stock split. Recipient: next WKNep.	

Annex 4: Stock annexes

The table below provides an overview of the stock annexes updated at WKNEP. Stock Annexes for other stocks are available on the ICES website Library under the Publication Type "Stock Annexes". Use the search facility to find a particular stock annex, refining your search in the left-hand column to include the *year*, *ecoregion*, *species*, and *acronym* of the relevant ICES expert group.

Stock ID	Stock name	Last updated	Link
Nep-3-4	Norway lobster (*Nephrops norvegicus*) in Division 3.a, FU3 and 4 (Skagerrak and Kattegat)	May 2014	*Nephrops* FU3&4
Nep-32	Norway lobster (*Nephrops norvegicus*) in Division 4.a, FU32 (northern North Sea, Norway Deep)	November 2016	*Nephrops* FU32
Nep-2324	Norway lobster (*Nephrops norvegicus*) in divisions 8.a and 8.b, FU23–24 (northern and central Bay of Biscay)	October 2016	*Nephrops* FU23–24
Nep-30	Norway lobster (*Nephrops norvegicus*) in Division 9.a, FU30 (Atlantic Iberian waters East and Gulf of Cadiz)	October 2016	*Nephrops* FU30

Annex 5: Comments from external experts

Comments on the 2016 *Nephrops* Benchmark are offered from the perspective of a review of the information presented on proposed methodology for assessing the stocks and providing input to the advisory process. While there was not adequate time to fully evaluate all data and methodological details, the reviewers scrutinized the presented material and suggested improvements where relevant. A number of comments regarding these are offered below.

Over some years, there has been a development towards UWTV surveys as the main source of information about stock abundance for *Nephrops* in European waters. The present workshop considered that approach for two new stocks, in FU 23–24 and FU30, and amendment of the existing assessment for FU 3–4. The status of FU 32 was also considered, but any reliable assessment for this stock is out of reach due to the lack of data. FU 28–29 was also scheduled for the present benchmark but had to be postponed to finalize necessary preparatory work.

For each of the stocks with UWTV surveys, the group considered in detail:

- the technology of the survey, including correction for edge effects, discovery rate, species identification, etc.;
- the distribution area and coverage;
- the derivation of a recommended harvest rate.

For all these stocks the WGNEP considered, and the reviewers endorsed, that with regard to the first two bullet points, the UWTV survey based assessment as described could be standard for the future. When attempting to derive reference points, with what is deemed to be an accepted method for such stocks, unexpected problems were uncovered that could not be solved at the meeting. This is further discussed below.

For FUs 3–4, UWTV surveys have been used for several years to assess the stock, and the present benchmark was mostly to endorse improvements and refinements. The WKNEP agreed that the proposed changes were acceptable.

Some specific issues:

Reference points

The key reference point for managing a stock with UWTV survey assessment is the recommended harvest rate, as a measure of exploitation. The guidance for that should be a proxy for F_{MSY}, which may be $F_{0.1}$, $F_{35\%SPR}$ or F_{max} if that is sufficiently well defined. The approach, in line with what has been done for other stocks, was to use a length-based steady state population model to obtain yield per recruit. The main tool used was the SCA software, which is a standard length-based equilibrium model with fixed parametric selection that is fitted to the length distribution of the catches. For a number of other stocks, one can simply calculate a yield per recruit from growth and selection parameters and assumed natural mortalities, with what appears to be sensible parameter values according to literature and occasional local observations. These may not be well parameterized, but tend to give reference points that are in line with what would commonly be regarded as reasonable.

For the stocks in FU 23–24 and FU 30, WKNEPH compared the abundance estimates from the SCA model with those estimated by the survey, and found large differences.

As a result, harvest rates derived from the SCA lead to much larger recommended catches than experienced historically because of the larger population estimate from the UWTV survey. The problems could be amended to a variable extent in numerous ways, but in particular by increasing the natural mortality in the SCA model, which again would have an impact on the reference points and subsequently on the harvest rate to be recommended.

It was also realized that the length distributions, in particular in FU30, declined stepwise towards larger length, which would not be compatible with constant growth and mortality for those lengths. Attempts to estimate mortality with the Jones cohort analysis indicated a declining F towards larger lengths for both sexes, although with different patterns, which, assuming a constant natural mortality, violates the assumption of flat selection-at-length. For FU3–4, two different but similar models were applied (SCA and SLCA) and the results were comparable.

The WKNEP found the issue of poor model fits (assuming M of 0.2 and 0.3) severe enough to preclude a routine application of standard methods, as it was unable to decide on adequate growth and mortality parameters. Results suggested that M should have been higher, for example, in the order of 0.4–0.5. This is not unique to *Nephrops* stocks, and this was reaffirmed here. The model parameters originate from general literature and occasional local observation. To ensure consistent standards, the WKNEP decided to recommend initiating the development of common guidelines for how to derive MSY and precautionary reference points for the exploitation of *Nephrops* that are assessed with UWTV surveys.

The conclusion, which was supported by the reviewers, was to present reference points derived from historical experience from similar previously assessed stocks as an interim solution. While these harvest rates were chosen deliberately on the precautionary side, their application still imply a major increase in landed catch, given that the UWTV surveys currently indicate that both these stocks are lightly exploited. A gradual transition towards higher TACs was recommended, but the exact design of such a regime would have to consider economic and social aspects that are outside the remits of the benchmark group.

Part of the SCA model output is an estimate of the absolute stock abundance. This method gave stock estimates far below those of the UWTV survey. While a reasonable fit could be obtained, the SCA model typically required a higher natural mortality than normally assumed for European *Nephrops* stocks. However, a new length-based methodology has been developed to estimate F and M simultaneously for multiple *Nephrops* stocks. When five *Nephrops* stocks were input into this hierarchical mean length and effort model, new estimates of M were produced for each stock and sex. These results also suggested that higher natural mortalities may be required for four out of five stocks.

Therefore, there clearly are indications that the natural mortality may be higher for some *Nephrops* stocks than previously assumed. However, there is not only uncertainty in the values of natural mortality, but also in the assumed growth parameters and the shape of the length selectivity in the fishery. All of these factors can affect the shape of the catch-at-length distribution, and in the SCA model, can produce different magnitudes of stock abundance.

WKNEP spent some time considering if high Ms on the order of 0.4 and higher could be valid, and in fact, where the original assumption of 0.2 and 0.3 came from. Although a higher natural mortality may be realistic, this requires further validation given that natural mortality is so poorly known. It is recommended that this is done as part of a broader exploration of methods to translate UWTV measured abundance into advice, by harvest rates derived from yield per recruit or by other approaches.

There is also a concern that the higher natural mortality assumption may lead to unwarranted increases in exploitation, as $F_{0.1}$ goes up with a higher M.

Spatial definition

On some occasions, areas that were not covered by the surveys were identified. It was agreed that if these areas contributed little to the fishery and hence the total stock abundance, then they should be ignored. While this may lead to a small underestimate of the total stock, it would not be unduly restrictive to the fishery. The alternative would be to postpone the transition to UWTV survey assessments, which was not recommended.

Survey index

In relation to FU 32, the WKNEP requested that estimates of relative biomass be presented at a finer spatial scale. Originally, the index was modelled with Skagerrak and the Norwegian Deep as having combined trends. The index was recreated with the two areas separated, and reviewed by the group. The results from the two runs were similar, but WKNEP concluded that the separated area approach was more appropriate.

Life-history parameters

It became clear that the uncertainty in life-history parameters (growth, natural mortality) for *Nephrops* is contributing to current model outputs. Therefore, the reviewers suggest future consideration of regionally-specific estimates of growth (specifically von Bertalanffy growth parameters) that reflect local population dynamics. Additionally, results from the hierarchical mean length and effort model suggest that natural mortality can be highly variable for *Nephrops*, and that for several functional units it may be higher than the 0.2 and 0.3 that was previously assumed. Thus, in the future it would be useful to validate natural mortality of *Nephrops* at the functional unit level.

For FU 30, there is some question about sample sizes in the lengthfrequency distributions, and the data appear to be quite noisy. Given the high dependence of length frequencies in length-based models (the SCA model as well as others), there's a continued need to ensure appropriate samples as data input.

Conclusions

For the stocks in FU 23–24 and FU 30, the reviewers conclude that the UWTV survey method, as described in the stock annex is appropriate for providing scientific advice on the abundance of these stocks, Likewise, the amended UWTV survey method for FU 3–4 is appropriate for the same purpose. However, for all these stocks, the reviewers agree that for deriving reference points, and hence translate the stock abundance estimate to recommended removals, the common length-based yield per recruit method is not appropriate. The reviewers agree that deriving harvest rates from historical experience and from experience with similar stocks, as suggested by WKNEP is acceptable as an interim solution, until a firmer basis for generating advice from UWTV survey abundance estimates can be developed.

For FU 32, the reviewers conclude that any reliable assessment is out of reach due to the lack of data. Survey information that was presented may be useful for monitoring purposes.