Porcupine Bank *Nephrops* Grounds (FU16)

2012 UWTV Survey Report and catch options for 2013

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Abstract

This report provides the results of the first underwater television on the 'Porcupine Bank *Nephrops* grounds' ICES assessment area; Functional Unit 16. The survey was multi-disciplinary in nature collecting UWTV, CTD and other ecosystem data. The UWTV results and a scientific basis for survey based catch advice in 2013 are presented. In total 47 UWTV stations were successfully completed. The mean burrow density was 0.19 burrows/m² (empirical 95% confidence intervals are from 0.17-0.21). The final krigged abundance estimate was 992 million burrows with a relative standard error of 5% and an estimated stock area of 7,100km^2. This abundance estimate can be considered as a conservative estimate given that the spatial coverage of the southern part of the ground was not complete. A correction factor of 1.26 is proposed based on expert judgments of burrow size and potential detection and identification biases. A yield and spawner per recruit analysis was used to estimate a harvest rate of 5.0% for the combined sex $F_{0.1}$ and other F reference points. This harvest rate is low compared to other FUs and can be considered very conservative. Applying this harvest rate to the abundance observed in the survey and using a mean weight in the landings of 45.0g implies landings in 2013 of 1,770 t. The results here could form the basis of the catch advice for 2013.

Key words: *Nephrops norvegicus*, Porcupine Bank, stock assessment, geostatistics, underwater television (UWTV), benthos.

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Introduction

The prawn (*Nephrops norvegicus*) are common around the Irish coast occurring in geographically distinct sandy/muddy areas where the sediment is suitable for them to construct their burrows. The *Nephrops* fishery in VII is extremely valuable with 2011 landings worth in excess of € 70 m at first sale. The *Nephrops* fishery on the Porcupine Bank takes place on a large area approximately 7,100 km² of complex muddy habitat between depths of between 330-570m. The fishery typically yields very large individual *Nephrops* that attain very high market prices relative to other fisheries around Ireland. International landings from the fishery peaked in the early 1980s around 4,000 tonnes but have shown a declining trend since then with some fluctuations (ICES, 2012a). The total estimated landings in 2011 were 1,187 t which were likely to be worth in the region of €15m.

In the recent past sustainability of the fishery has been a major concern. Consequently a spatio-temporal closed area which was developed and proposed by the NWWRAC has been introduced for three months each year since 2010. As part of the TAC regulation a functional unit catch limit (actually landings) was introduced since 2011 (ICES, 2012b). These management measures were introduced due to negative trends in the various indicators used to assess the stock and ICES advice for a closure of the fishery in 2009 and 2010 (ICES, 2012a). The stock situation is known to have improved significantly since 2010 following a good recruitment. Estimates of stock size or appropriate “MSY” exploitation rates have not been available to date. The scientific data for this area has improved recently with the introduction of a dedicated fisheries science survey since 2010 and the provision of commercial grade information by the fishing industry since 2010. In July 2012 ICES provided advice based on an approach for “data poor” stocks which states that catches should be less than 1,100 t in 2013.

Nephrops spend a great deal of time in their burrows and their emergence behaviour is influenced many factors; time of year, light intensity and tidal strength. Underwater television surveys to monitor the abundance of *Nephrops* populations was pioneered in Scotland in early 1990s. Since then regular surveys have been conducted for many of the main *Nephrops* fisheries around Britain and Ireland (ICES, 2010). The technique has also been used in Danish, Greek, Italian and Spanish waters (ICES, 2012c). Historically either length cohort analysis (LCA) or tuned age-based assessments (XSA); where annual length distribution were sliced into pseudo-age groups, formed the basis of the assessment and management advice for *Nephrops*. These methods performed relatively poorly due to the generally insensitive nature of LCA to underlying stock and fishery dynamics and the lack of convergence in the VPAs. There were additional concerns about representativeness of *Nephrops* LPUEs and tuning data as well as considerable uncertainty about accuracy of growth parameters and landings statistics in some areas.

A more direct approach of using the UWTV surveys and applying harvest ratios (HRs) was proposed by Dobby & Bailey in 2006. Initially concerns about the accuracy of the UWTV surveys meant this approach was not widely accepted. WKNEPH 2007 discussed and documented the various uncertainties with UWTV surveys and further developed the HR approach (Dobby *et. al* 2007, ICES, 2007).

Various studies were then carried out to investigate and mitigate uncertainties in the UWTV survey methodologies (e.g. Campbell et al 2009, ICES 2008 & 2010).

In 2009 WKNEPH debated the use of the surveys as either an absolute measure of abundance or a relative index relative (ICES, 2009a). Ultimately this led to a consensus that bias corrected survey abundance estimates could be used directly in the formulation of catch advice. Two modelling approaches were used to estimate sustainable stock specific Harvest Ratio reference points; SCA (a separable LCA model Bell) & Age Structured Simulation model (Dobby) (ICES, 2009a). Various harvest ratios are applied to bias corrected UWTV abundance, mean catch proportions retained and mean weight in the landings to give catch options in weight at different HRs. Stock specific F_{msy} proxies ($F_{0.1}$, $F_{35\%\ SPR}$, F_{max}) are chosen depending on biological characteristics, level of scientific knowledge and history of exploitation. While some concerns still remain, this approach has served to stabilise and standardise the production of catch advice for *Nephrops* stocks where UWTV surveys exist. One considerable advantage of this approach is that it can be applied to a single year's UWTV survey and does notnecessarily require a long time series to be useful.

This was the first comprehensive UWTV survey of the Porcupine Bank *Nephrops* grounds (FU16). The survey was multi disciplinary in nature; the specific objectives are listed below:

1. To obtain 2012 quality assured estimates of *Nephrops* burrow densities from a randomised isometric grid of UWTV stations at 6 nautical mile spacing over the known spatial and bathymetric distribution of the stock (Figure 1).
2. To collect ancillary information from the UWTV footage collected at each station such as the occurrence of sea-pens, other macro benthos and fish species and trawl marks on the sea bed.
3. To collect oceanographic data using a sledge mounted CTD.
4. To generate stock abundance estimates and propose suitable correction factors for this area.

This report details the final UWTV results of the FU16 2012 survey. Full detail of the results from other data collected during the survey will be available in the final survey report. In order to use the UWTV abundance estimate from the survey stock specific harvest ratios for the various different F reference points are required. The results of a LCA and yield per recruit analysis are also presented here. The basis for the mean weight in the landings assumption is described and discussed. Finally conservative catch options for 2013 using stock specific reference points are provided.

Material and methods

A randomised isometric gird of stations at 6 nautical mile or 11.1km intervals was planned for the area. The boundary use to delineate the edge of the ground was based on VMS data of fishing activity between 2006-2011 targeting *Nephrops* (where >30% of daily operational landings was reported to be *Nephrops* using the methods described in Gerritsen & Lordan 2011) (Figure 1). The grid spacing was determined based on a time constraints of getting the survey completed within a time window of around 5 days. This resulted in 68 planned stations. Data on bathymetry and backscatter were also available from the Irish National Seabed Survey and INFOMAR project (http://www.infomar.ie/). The stations ranged from 340-560 m in depth with an average depth of around 440 m (Figure 1).

The protocols used were those reviewed by WKNEPHTV 2007 (ICES, 2007) and employed on other UWTV surveys in Irish waters. These protocols can be summarised as follows: At each station the UWTV sledge was deployed and once stable on the seabed a 10 minute tow was recorded onto DVD. Time referenced video footage was collected from two video cameras giving fields of view or 'FOV' of 75 cm and 105 cm. Vessel position (DGPS) and position of sledge (using a USBL transponder) were recorded every 1 to 2 seconds. The navigational data was quality controlled using an "r" script developed by the Marine Institute (ICES, 2009b). The USBL navigational data was used to calculate distance over ground or 'DOG' for all of stations.

In line with SGNEPS recommendations all scientists were trained/re-familiarised using training material and validated using reference footage from the Aran grounds, the nearest *Nephrops* ground to the Porcupine Bank, prior to recounting at sea (ICES, 2009b). Figure 2 shows individual's counting performance in 2012 against the reference counts as measured by Linn's concordance correlation coefficient (CCC). A threshold of 0.5 was used to identify counters who needed further training. Once this process had been undertaken, all recounts were conducted by two trained "burrow identifying" scientists independent of each other on board the research vessel during the survey. During this review process the visibility, ground type and speed of the sledge during one-minute intervals were subjectively classified using a standard classification key. The numbers of *Nephrops* burrows complexes (multiple burrows in close proximity which appear to be part of a single complex are only counted once), *Nephrops* activity in and out of burrows were counted by each scientist for each one-minute interval was recorded. Although SGNEPS recommended that verification recounts should be 7 minutes (ICES, 2009b) this was increased to 10 minutes for the Porcupine. This was because at the lower densities observed the relative scale of variation between minutes was higher than typical in other areas. Recounting more minutes resulted in a more stable mean density estimates for each station.

Notes were also recorded each minute on the occurrence of trawl marks, fish species and other species. Numbers of sea-pen species were also recorded due to an OSPAR Special Request. Finally, if there was any time during the one-minute where counting was not possible, due to sediment clouds or other reasons, was also estimated so that the time window could be removed from the distance over ground calculations. The "r" quality control tool allowed for individual station data to be analysed in terms of data quality for navigation, overall tow factors such as speed and visual clarity and consistency in counts (an example is given in Figure 3). Consistency and bias between individual counters was examined using Figure 4. There were no obvious problems.

The recount data were screened for one minute intervals with any unusually large deviation between recounts. Mean density was calculated by dividing the total number of burrow systems by the survey area observed. All recounts were carried out on the footage with an FOV of 75cm. This assumes that the sledge was flat on the seabed (i.e. no sinking). This field of view was confirmed for the majority of tows using lasers during the 2012 survey. Although footage with a FOV of 105cm was collected during the survey verification recounts were not. The experience scientists found the footage with an FOV of 75cm easier to recount than the FOV of 105cm. Burrow systems were relatively large and occurred at low density making the verification recounts relatively easy. Figure 5 shows the variability in density between minutes and operators (counters) for each station. These show that the variability between minutes was high reflecting the patchy low density and consistency between counters was very high reflecting the fact that burrow identification was relatively easy.

To account for the spatial co-variance and other spatial structuring a geo-statistical analysis of the mean and variance was carried out using SURFER Version 10.7.972. The mid-points of each UWTV transect were converted to meters using UTM zone 28. Given that this was the first survey in the area full spatial coverage of the stock area was not achieved a number of assumptions needed to be considered and explored. There were no UWTV observations adjacent to boundaries in the south of the ground and densities at the southern range of observations were relatively high. Extrapolating these high densities through krigging to the boundary would be a strong and not very conservative assumption. Information for trawl surveys indicated that relative catch rates (CPUEs) declined towards this southern boundary (Stokes and Lordan, 2011, González Herraiz, 2011). A pragmatic conservative solution would be to assume zero densities for grid points past the ground boundary as defined in Table 1. This forces the kigged burrow surface towards zero at the south of the *Nephrops* ground where there were no UWTV survey observations. These assumed zero density points are shown in Figure 7.

It was not considered appropriate to constrain the densities north of the area as there were UWTV observations of relatively high densities close to the boundaries and the burrow surface appears to be fairly homogeneous. It is more likely that the transition from *Nephrops* habitat to non-*Nephrops* habitat is relatively sharp and well defined by the *Nephrops* directed fishing activity as defined using VMS. Several different krigging models were explored using the 47 observed stations and the 30 assumed zero density for grid positions beyond the boundary. An unweighted and unsmoothed omnidirectional variogram was constructed with a lag width of approximately 3.1km and maximum lag distance of between 79 km. A model variogram was produced with a logarithmic model was fitted using the SURFER algorithm. Various other experimental variograms and model setting were examined before the final model choice was made.

The resulting variograms was used to create krigged grid file of interpolated burrow density. The final part of the process was to limit the calculations to the known extent of the ground using a boundary blanking file (Table 1). The resulting blanked grid was used to estimate the domain area and total burrow abundance estimate. Krigged estimation variance or CV was carried out using the EVA: Estimation VAriance software (Petitgas and Lafont, 1997). The EVA burrow abundance estimates were extremely close to the Surfer estimate.

In addition a CTD profile was logged for the duration of each tow using a Sea-Bird SBE37. This data will be processed later.

Results

The density estimates by station are given in Table 2. A histogram of the observed burrow densities for 2012 on the Porcupine Bank is shown in Figure 6. The mean burrow density for the observations was 0.19 burrows/m² (empirical 95% confidence intervals are from 0.17-0.21). The range of the observations was relatively high from 0.02-0.45 burrows/m² (Table 3). The spatial distribution of burrow observations is shown as a linear scaled bubble plot in Figure 3. There was no strong spatial pattern or trend to the burrow densities. A few stations on the western edge (25, 20, 18) and the most eastern station (17) had low densities. In other areas densities were quite similar (around the average) with a few low or high observations e.g. stations 20 and 33.

The final modelled density surface is show as a heat map in figure 7. The impact of the zero density assumptions for grid nodes past the ground boundary can be clearly seen. The burrow densities decline towards zero towards the south of the area. The abundance estimate derived from this krigged burrow surface was 992 million burrows. The estimated area of the ground or domain area was 7,108km². The estimation uncertainty on the abundance was around 5%. Scaling the mean burrow density to the entire surface area of the ground would yield and abundance of 1,351 million (1.2-1.5 billion burrows with 95% Confidence Intervals) with a relative standard error of 41%.

Trawl marks were observed at 32% of surveyed stations and 9% of surveyed stations had trawl marks persisting throughout the 10 minute transect. Various epibenthic and macrobenthic species were observed during the survey and the species composition was quite different to other *Nephrops* grounds routinely surveyed by Ireland. A more detailed analysis of the benthic communities is currently underway and will be included in the final report.

Porcupine Bank *Nephrops*: Separable Length Cohort Analysis & Estimation of Per Recruit Reference Points

The selectivity parameters required for the per recruit analysis are derived from a combined sex separable length cohort analysis. The approach used was detailed in Dobby *et. al* 2007 and applied to other *Nephrops* stocks by WKNEPH in 2009 (ICES, 2009). This model assumes that fishing mortality is separable into a length dependent (logistic ogive) and time dependent component with a catchability multiplier for mature females.

An LCA was fitted to the 2010-2011 catch length distribution data as shown in Figure 8. The growth, natural mortality and maturity input parameters were taken for the Stock Annex for Porcupine *Nephrops* and are given in Table 4. It is normal practice of ICES Working groups to use an average length frequencies over three years for the LCA but in the case of Porcupine *Nephrops* there was sparse sampling in 2009 so the length distribution was averaged over two years. An alternative LCA which used the full time series of length frequency data (1986-2011) was also explored. The relatively poor model fit to the 2010-2011 data could be due to a number of reasons including:

- Incorrect biological parameters
- Inappropriate assumptions about selection pattern (i.e. could it be more dome shaped for females)
- The LFDs not being from a stock in anywhere near equilibrium – main peak consisting of potentially 1 year class, 2nd peak in males at 60 mm the remains of some much older cohorts.

It is worth noting that the alternative LCA using the full time series of length frequencies resulted in fairly similar fishery inputs (k = 0.42 and L50 = 35.65) and also resulted in a better fit. This strongly suggests that the poor fit is because the stock is not in equilibrium. Despite the poor fit, the parameter estimates based on the 2010-2011 LCA were used in the length-based age structured per recruit analysis (Table 6). The same biological parameters and assumptions about logistic selection etc as the LCA were also used.

The model runs with a monthly time-step (best way for making lengths almost continuous) and the F-multiplier steps in increments of 0.01. The resulting YPR and SPR plots are shown in Figure 9 and summary of potential reference points and associated harvest rates in Table 6. Actual YPR and SPR values are much higher than other FUs. The biological parameters imply bigger and much heavier individuals particularly the females in this FU.

The harvest rate equivalent to fishing at combined sex $F_{0.1}$ is 5 % (Table 6).

Sensitivity Analysis

WKFRAME highlighted that YPR is sensitive to the biological and fishery input parameters and emphasized that a sensitivity analysis should be carried out. The main sensitivity testing here was in relation to the L_{50} and M. Previously Dobby (unpublished) explored sensitivity to density dependent growth and Female relative catchability. Given that densities are low relative to other FUs and the fishery is normally around 80% male sensitivity to these parameters are less relevant for Porcupine *Nephrops*.

L_{50}

The low number of small individuals in the LFDs results in a high L_{50} selection parameter in comparison to other FUs (Table 5). An exploration of the historic length frequency data and more recent survey data suggest that this high fishery selection is a feature of Porcupine *Nephrops*. Figure 10 shows how the harvest rate, F-multipliers and male Fbar and % SPR equivalent to fishing at MSY (combined sex F_{max}, $F_{35\%}$ and $F_{0.1}$) vary with L50s in the range 20 – 40 mm. A lower L50 obviously implies greater harvest rate and a reduction of 10 mm to 22 mm, which is common in most other stocks, results in a harvest rate (at $F_{0.1}$ combined) of approximately 7%.

Natural mortality

In contrast to other FUs the natural mortality has been assumed to be the same across the whole population – i.e. including mature females. It has been thought that M for this deepwater stock may be lower than other FUs although the decline of the numbers with length in the landings LFD could be an indicator of relatively high M (for females anyway). The natural mortality has relatively little impact on the estimate of harvest rate at $F_{0.1}$ (in this case) but a much greater impact on the estimates at F_{max} and $F_{35\%}$.

Mean weight in the Landings

An estimate of mean weight in the landings is required to calculate catch options using the methodology developed by WKNEPH (ICES, 2009). In the case of Porcupine Bank *Nephrops* there has been significant change in mean weight linked to the decline in the stock (Table 7). Prior to 2000 the mean weight was relatively stable fluctuating around 45gr. There was a significant increase in mean weight during the period 2000-2006 due to and increasing reliance on older larger individuals in the fishery. Due to the strong recruitment observed the mean weight has subsequently declined to just over 45gr again in 2011. Information from the fishery thus far in 2012 suggests that the mean weight in 2012 is similar or slightly higher than 2011. A lower mean weight assumption in the derivation of catch options is more conservative. Therefore a mean weight of 45gr is proposed in the calculation of catch advice for 2013.

Discussion

This was the first systematic UWTV *Nephrops* survey of the Porcupine Bank. The distance from shore (~ 120 nautical miles), exposed nature of the area, the significant water depths involved (330-570m) and relatively large size of the area (>7100km^2) presents significant logistical, technical and survey design challenges. The first and most important finding was that it was technically feasible to carry out the survey and that on average it took around 2 hours to complete each station (excluding any technical or weather related downtime). Once on the sea bed the UWTV sledge system preformed well. Ground contact and speed over ground was good. The visibility was normally excellent (except where vessels were active nearby). Burrow morphology and size ranges encountered were very similar to other areas. The relatively low density and large nature of the burrow openings meant that burrow identification was relatively easy.

A survey design using a randomised isometric grid was planned with 68 stations inside the probably stock area. The stock area itself is pretty well defined using integrated VMS-logbook data (Gerritsen & Lordan, 2011). Unfortunately only 47 of the planned stations could be completed in the weather window available for the survey. One of the drawbacks of this approach is that some assumptions must be made to fill in missing grid points if full survey coverage is not achieved. The krigged model applied here represents a fairly conservative approach. The resulting abundance estimate of just less than 1 billion burrows can be considered a minimum estimate for the area. An abundance estimate without the boundary constraints imposed in this krigged model would be similar to the product of the mean burrow density and area (~1.4 billion).

This new information on burrow density and abundance significantly improves the capacity for ICES to give management advice and catch options for FU16. In July, ICES used a “data limited approach” to propose that landings be limited to <1,100 t. The results of this survey could enable ICES to update it categorisation of this stock form data limited to so called “Category 1”. Previously, ICES has based advice and calculated catch options for stocks with one or two UWTV surveys using the methodology discussed in the introduction. For example the advice for FU19 in 2012 was based on a new survey in 2011 (ICES, 2012). The advice for FU14 for 2011 was based on two years of survey data (ICES 2010). ICES have also introduced an approach for data limited *Nephrops* stocks in 2012 whereby the best estimates of ground area, mean burrow density, discard rate and mean weight are used to explore if the average landings of the last ten years correspond to precautionary harvest rates. This approach was implemented for FU20-21, FU5, FU10, FU32, FU33 and FU34 in 2012 and forms the basis of the ICES advice.

Before the burrow abundance estimate can be used as an absolute measure of individuals in the population some correction factors have to be applied (ICES, 2009). For the Porcupine Bank the field of view of the camera was 0.75m and expert judgment of the mean burrow diameter was in the range of 0.55-0.65m. Using the simulation approach suggested by Campbell et al. 2009 the estimated edge effect bias was in the range of 1.24-1.28. This may seem low compared with other areas but it is based on the best judgement of burrow diameter from the footage. In the future it may be possible to quantitative estimate burrow diameter from mosaics of the footage from this and other areas. Burrow detection rates were thought to be relatively high and identification could be slightly over estimated. The proposed cumulative correction factor for the area was 1.26. This is compared with the correction factors applied in other areas in Table 8 and is quite close to the average used on other grounds.

Catch options for 2012 based on the survey abundance, mean weight estimate and harvest ratios at different stock specific F reference points are presented in Table 9. The number of observer trips in this fishery has been low (1-3/year since 2010) but all report negligible *Nephrops* discarding in this fishery. Therefore no discards have been included in the calculation of catch options. Using the ICES decision making framework the combined sex $F_{0.1}$ should be considered as an appropriate F_{msy} proxy. The associated catch option is 1,770 t for 2013.

Table 10 compares the Harvest Rate at $F_{0.1}$ for this and other ICES stocks. The Harvest Rate of 5% is significantly below that calculated for most other *Nephrops* stocks and can be considered very conservative. The only similarly low harvest rate at $F_{0.1}$ is for FU3&4 where catches are also mainly composed of relatively large *Nephrops*. The sensitivity analysis implies that the harvest rate at $F_{0.1}$ is fairly sensitive to the fishery selection parameter and the estimate for the Porcupine Bank is high compared to other stocks. Further explorations and analysis are planned for the ICES benchmark scheduled for early 2013. This may yield new insights into appropriate harvest rates for Porcupine *Nephrops*. In the interim the results here could form the basis of the catch advice for 2013.

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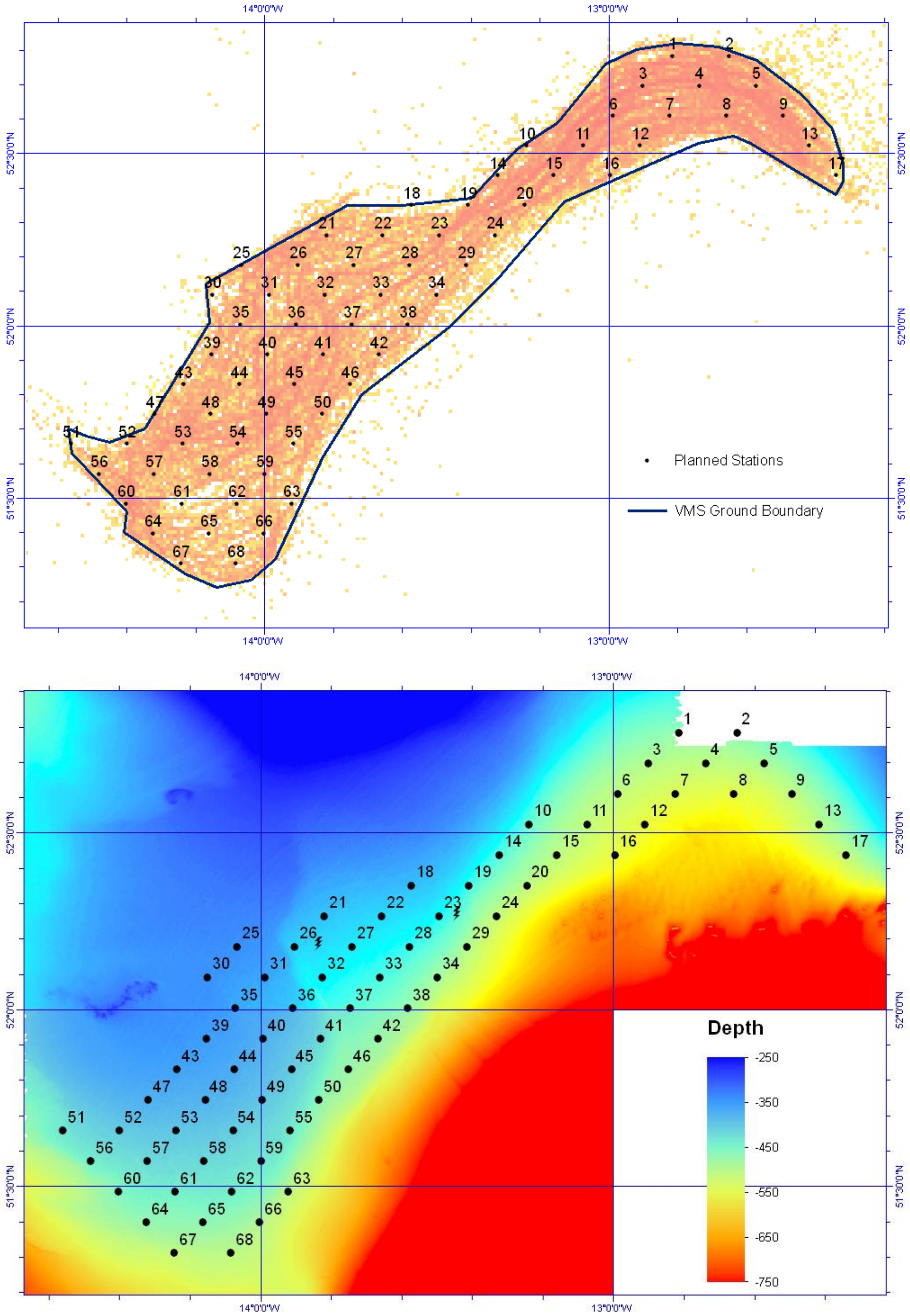


Figure 1: Porcupine Bank 2012 UWTV map of station positions overlaid on a heat map of *Nephrops* directed fishing (top panel) and bathymetry (bottom panel).

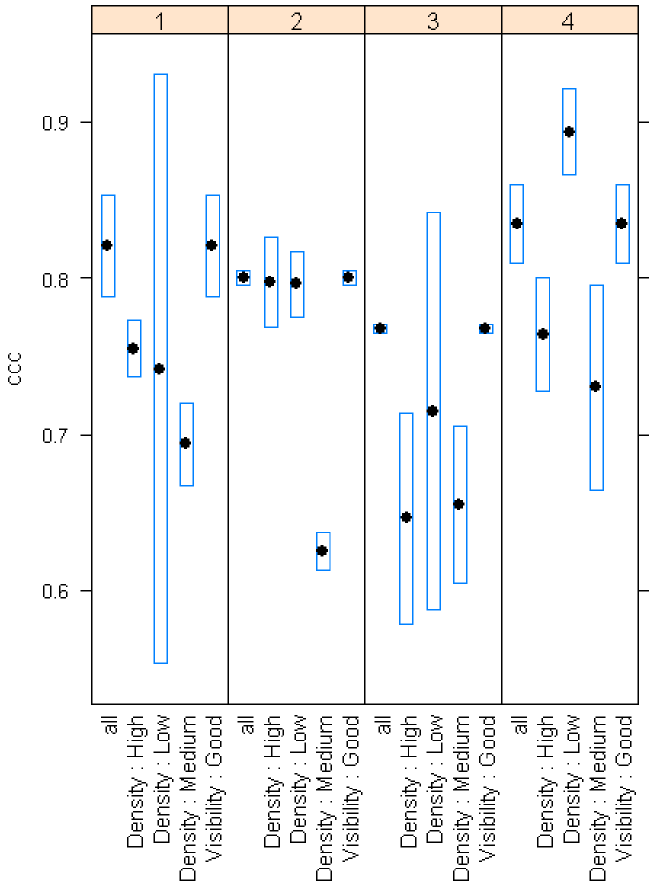


Figure 2. Porcupine Bank 2012 UWTV individual counting performance against the reference counts as measured by Linn's concordance correlation coefficient (CCC).

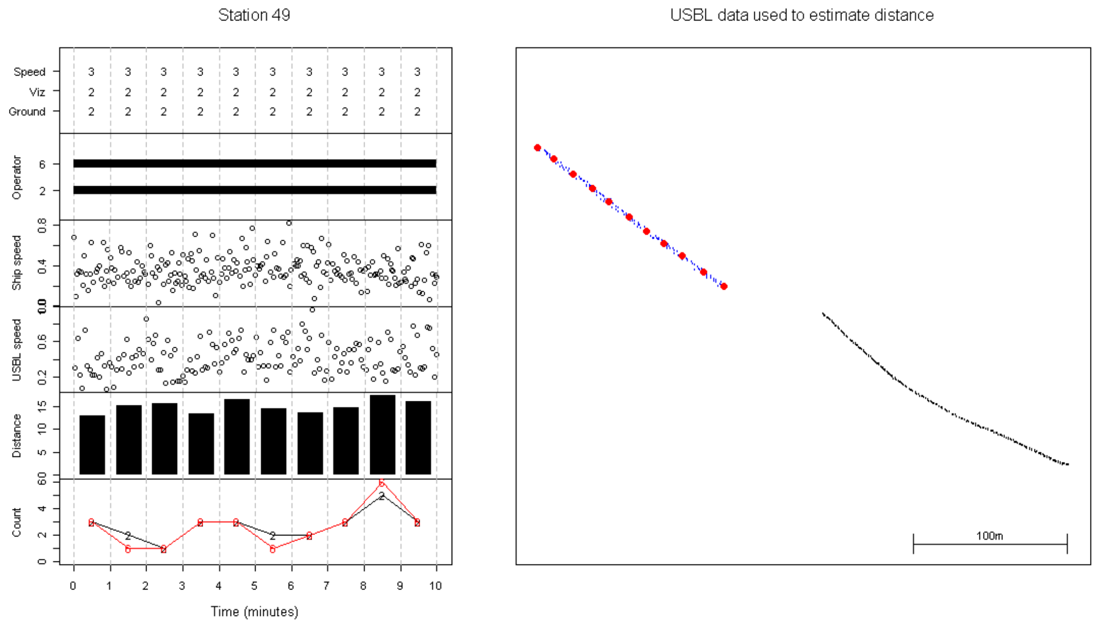


Figure 3. Porcupine Bank 2012 UWTV example quality control plot for the navigational and recount data.

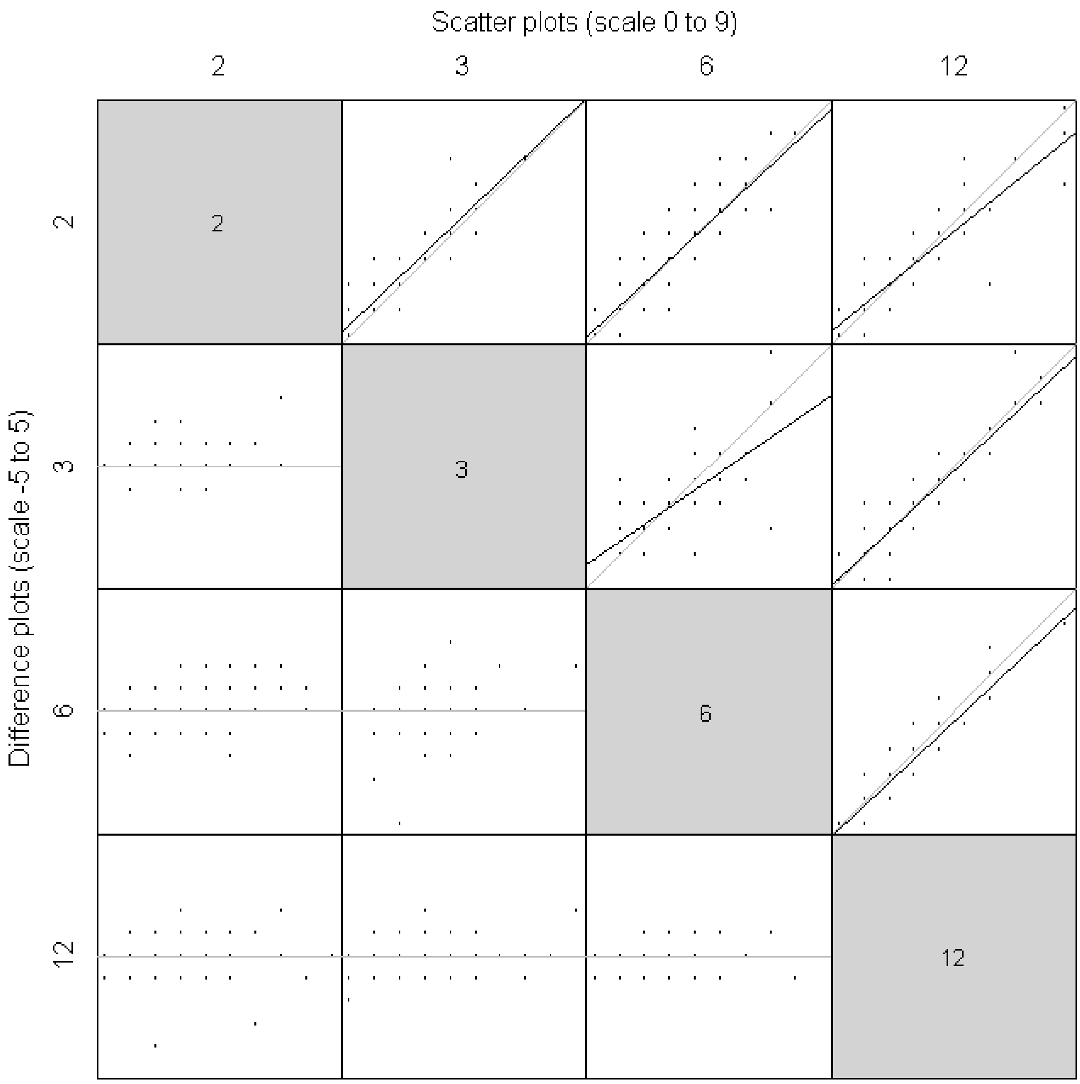


Figure 4 Porcupine Bank 2012 UWTV inter counter comparison plot.

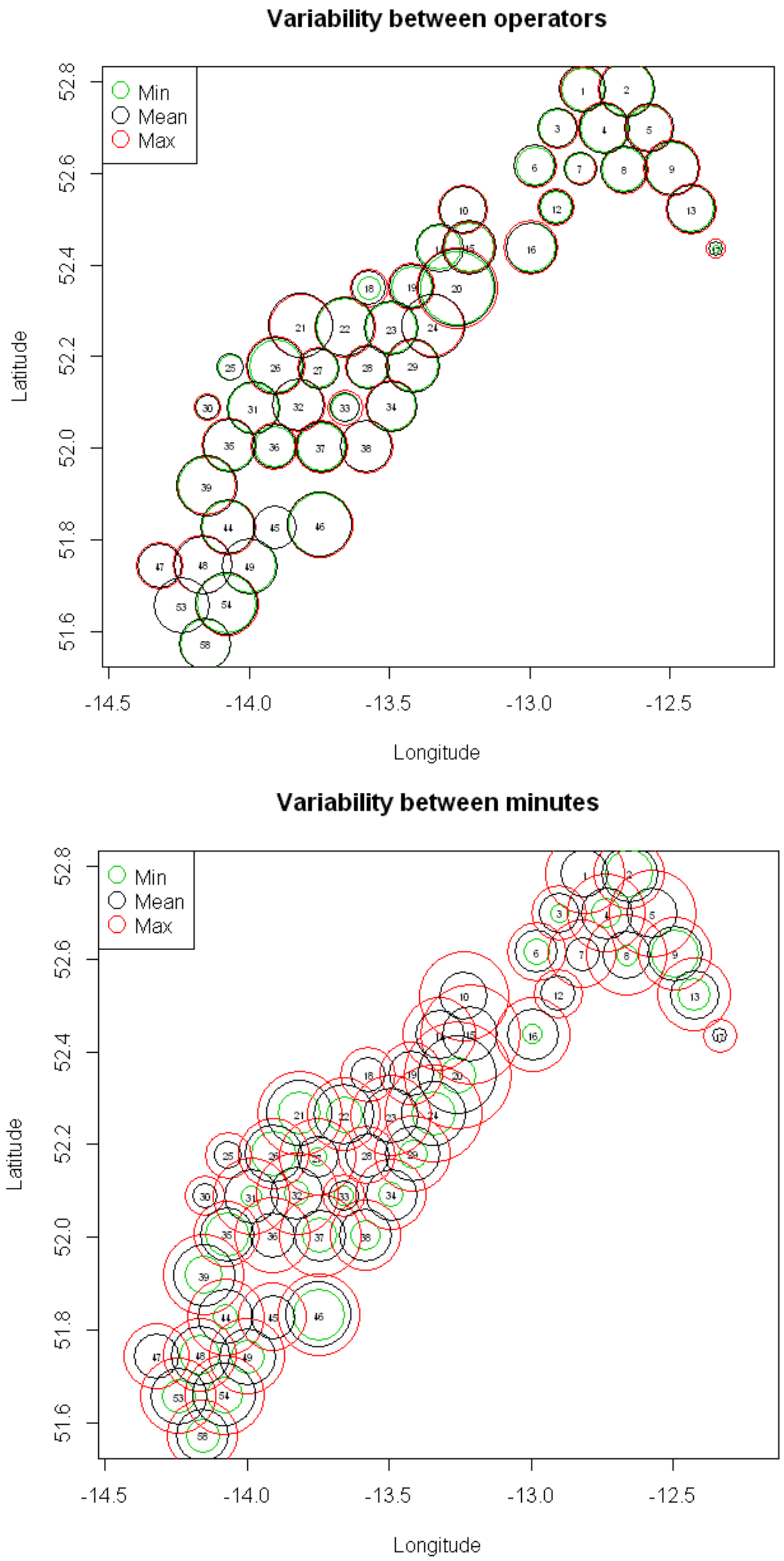


Figure 5: Porcupine Bank 2012 UWTV quality control plot showing variability between counters (top panel) and between minutes (bottom panel) for each UWTV station

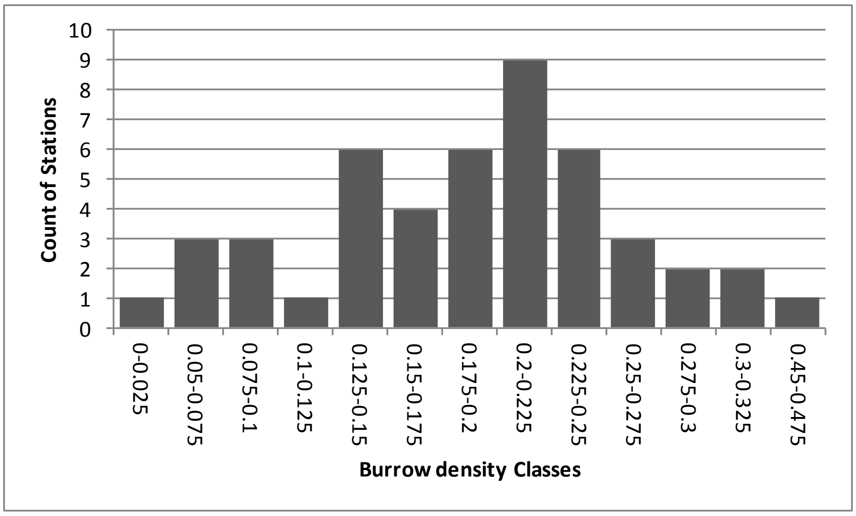


Figure 6: Porcupine Bank 2012 UWTV histogram of burrow density for the 47 observed stations.

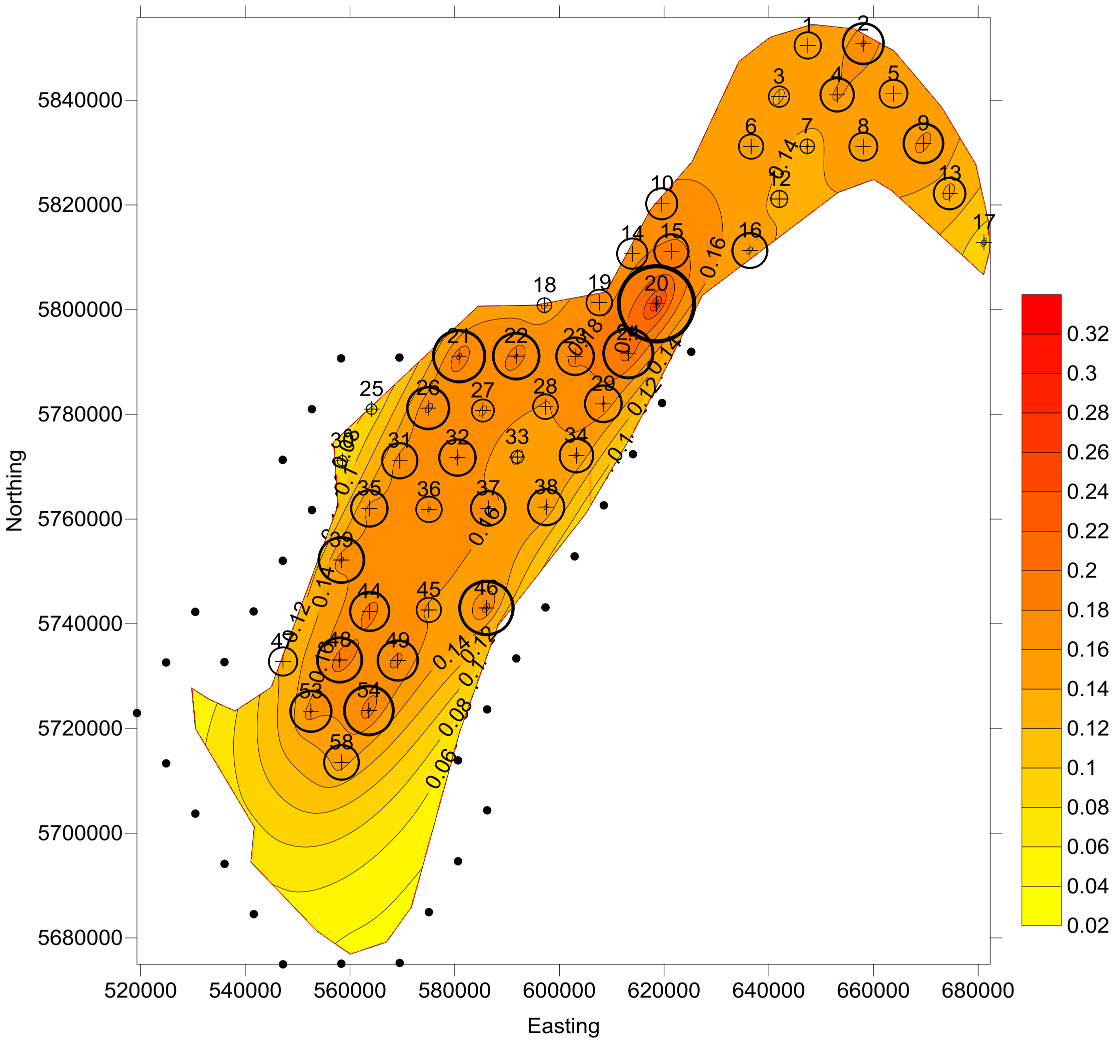
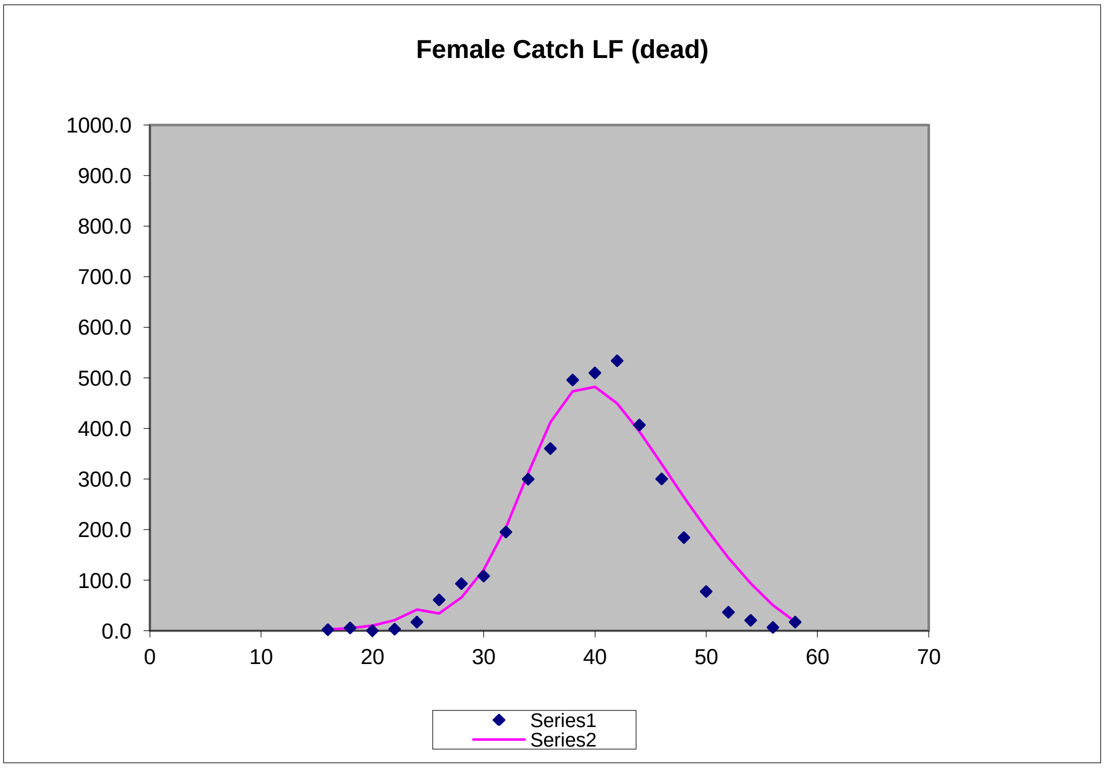


Figure 7: Porcupine Bank 2012 UWTV bubble plot of the burrow density observations overlaid on a head map of the krigged burrow density surface. Observed station positions are indicated using a + and assumed zero densities beyond the boundary are shown as black filled circle.



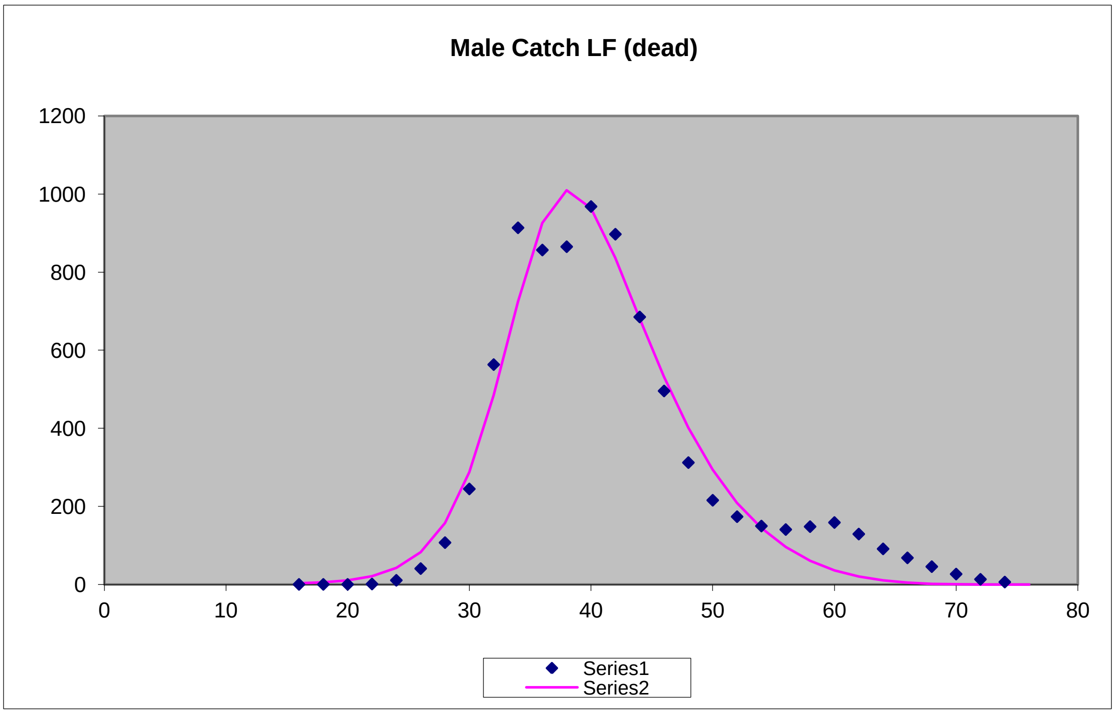


Figure 8: Porcupine Bank Separable LCA fit with growth parameters from the stock annex and LFD (2010-11)

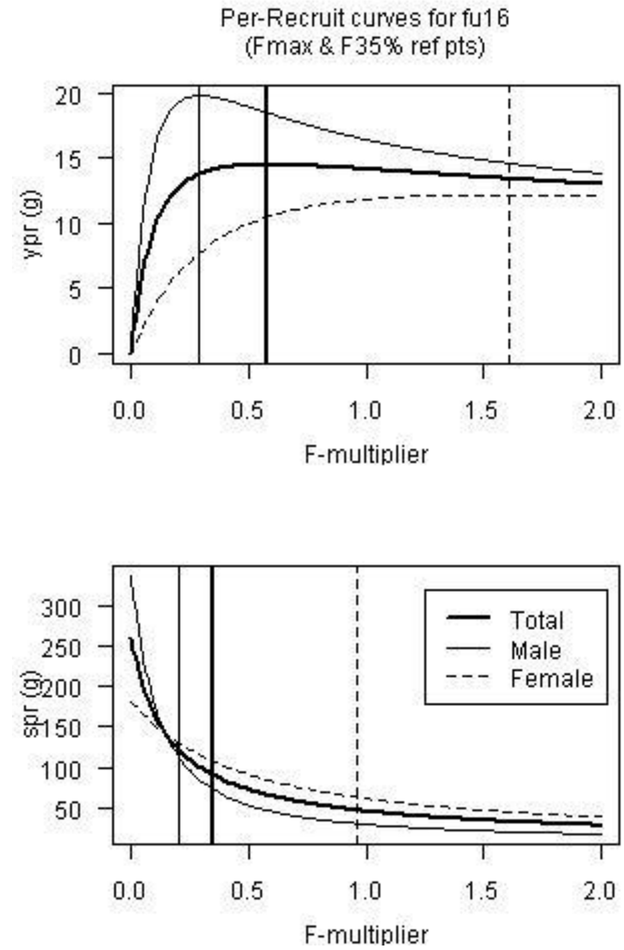


Figure 9 Porcupine Bank *Nephrops*. Yield-per-recruit and spawning stock biomass-per recruit for males, females (dotted line) and combined (bold) with F_{max} and $F_{35\%spr}$ reference points.

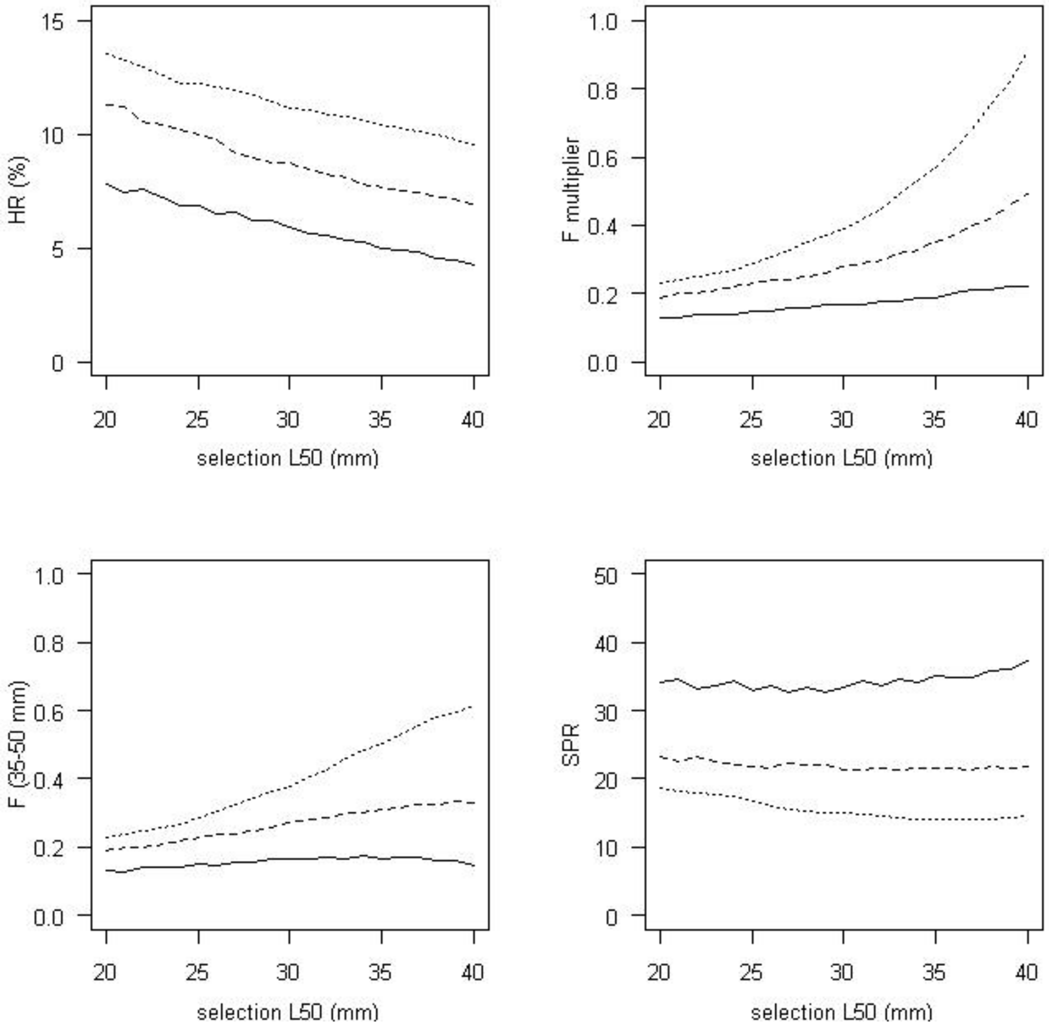


Figure 10. Sensitivity to changing length at 50% selection in logistic selectivity ogive a) MSY harvest rates, b) F-multipliers, c) male Fbar (over 35-50 mm) and d) male spawner per recruit (%). Solid line: F0.1 (combined sex), dashed line: F35% (combined sex), dotted line: Fmax (combined sex).

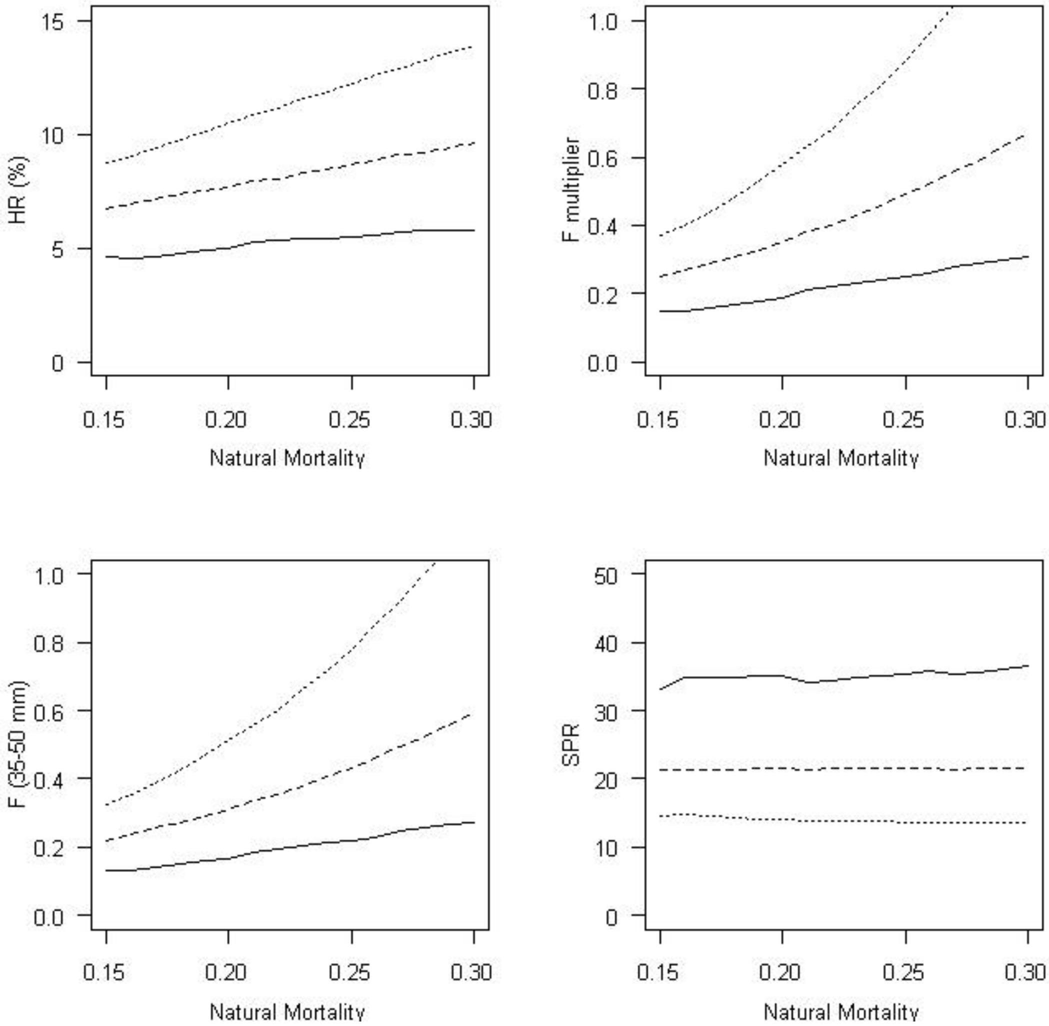


Figure 11. Sensitivity to changing natural mortality a) MSY harvest rates, b) F-multipliers, c) male Fbar (over 35-50 mm) and d) male spawner per recruit (%). Solid line: F0.1 (combined sex), dashed line: F35% (combined sex), dotted line: Fmax (combined sex).

Table 1: Porcupine Bank *Nephrops* ground boundary based on VMS activity for Irish vessels between 2006-2011.

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

Table 2. Density estimate by station for the 2012 Porcupine UWTV survey.

Station Number	AvgOfLatitude Decimal	AvgOfLongitude Decimal	DoG (m)	Area (m²)	Density (burrow/m²)	Burrow Count	Easting	Northing
1	52.78	-12.81	192.24	144.18	0.15	22	647447	5850476
2	52.78	-12.66	195.14	146.36	0.24	35	658054	5850805
3	52.70	-12.90	277.80	208.35	0.12	24.5	641957	5840695
4	52.70	-12.73	201.78	151.33	0.19	29.5	653056	5841039
5	52.70	-12.58	226.20	169.65	0.16	27.5	663819	5841247
6	52.61	-12.98	242.07	181.55	0.14	25.5	636624	5831150
7	52.61	-12.82	212.59	159.44	0.08	12.5	647346	5831191
8	52.61	-12.67	229.90	172.42	0.16	28	658066	5831138
9	52.61	-12.50	175.34	131.51	0.23	30.5	669550	5831761
10	52.52	-13.24	129.05	96.79	0.18	17.5	619556	5820230
12	52.52	-12.91	163.30	122.48	0.09	11.5	641998	5821143
13	52.52	-12.43	191.96	143.97	0.18	26.5	674546	5822187
14	52.43	-13.32	147.38	110.53	0.18	19.5	613933	5810701
15	52.44	-13.21	153.98	115.48	0.20	23	621399	5811149
16	52.43	-12.99	172.83	129.62	0.20	26.5	636388	5811293
17	52.44	-12.34	219.52	164.64	0.02	3	681104	5812858
18	52.35	-13.57	151.59	113.69	0.08	9	597136	5800839
19	52.35	-13.42	148.28	111.21	0.15	16.5	607623	5801355
20	52.35	-13.26	149.22	111.92	0.45	50.5	618552	5801132
21	52.26	-13.82	203.47	152.60	0.30	46.5	580847	5791114
22	52.26	-13.66	196.58	147.43	0.27	40	591746	5791127
23	52.26	-13.49	179.08	134.31	0.22	29.5	603003	5791093
24	52.26	-13.34	162.12	121.59	0.29	35.5	613174	5791680
25	52.18	-14.06	204.30	153.23	0.06	8.5	564121	5781002
26	52.18	-13.90	219.44	164.58	0.25	40.5	574938	5781191
27	52.17	-13.75	221.09	165.81	0.13	21	585387	5780734
28	52.18	-13.58	169.19	126.89	0.14	18	597334	5781468
29	52.18	-13.41	192.77	144.58	0.21	31	608397	5782019
30	52.09	-14.15	212.89	159.67	0.05	8.5	558522	5771141
31	52.09	-13.99	148.94	111.71	0.21	23	569505	5771153
32	52.09	-13.82	153.64	115.23	0.21	24.5	580527	5771749
33	52.09	-13.66	165.40	124.05	0.07	8.5	591953	5771852
34	52.09	-13.49	207.64	155.73	0.20	30.5	603255	5772124
35	52.01	-14.07	210.06	157.54	0.21	33.5	563698	5762037
36	52.00	-13.91	144.78	108.58	0.15	16	575090	5761854
37	52.00	-13.74	205.05	153.79	0.20	31	586415	5762043
38	52.00	-13.58	205.02	153.76	0.21	32.5	597482	5762275
39	51.92	-14.15	202.27	151.70	0.27	40.5	558357	5752181
44	51.83	-14.07	151.67	113.75	0.23	26	563760	5742359
45	51.83	-13.91	198.82	149.11	0.14	21	575056	5742642
46	51.83	-13.75	159.84	119.88	0.32	38	586063	5743020
47	51.74	-14.32	154.60	115.95	0.16	19	547203	5732800
48	51.75	-14.16	281.46	211.09	0.26	55.5	558018	5733084
49	51.74	-14.00	150.56	112.92	0.23	26.5	569129	5732984
53	51.66	-14.24	149.95	112.46	0.24	27	552541	5723279
54	51.66	-14.08	211.88	158.91	0.29	46	563602	5723449
58	51.57	-14.16	193.83	145.37	0.20	29.5	558377	5713528

Table 3: Summary of univariate statistics for the burrow density estimates on the Porcupine Bank UWTV survey in 2012.

Univariate Statistics	**Density estimates**
Number of Observations	47
Minimum:	0.018
25%-tile:	0.142
Median:	0.199
75%-tile:	0.235
Maximum:	0.451
Midrange:	0.235
Range:	0.433
Interquartile Range:	0.093
Median Abs. Deviation:	0.047
Mean:	0.190
Trim Mean (10%):	0.188
Standard Deviation:	0.079
Variance:	0.006
Coef. of Variation:	0.414
Coef. of Skewness:	0.371

Table 4: Biological input parameters for population model and LCA.

		Males					Females					
Name	FU	k	Linf	M	a	b	K	Linf	L Mat	M	a	b
Porcupine Bank	16	0.14	75	0.2	0.00009	3.55	0.14	75	26	0.2	0.00009	3.55
							0.14	60		0.2	0.00009	3.55

Table 5: Fishery input parameters for FU16 based on the LCA using 2010-2011 data and for other stock assessed by WGCSE and WGNSSK.

		Landings		Discards			Female
Name	FU	k	L50 (mm)	k	L50 (mm)	multiplier	relative q
Porcupine Bank	16	0.36	35.04	NA	NA	0	0.29
Farn Deeps	6	0.52	24.15	0.59	26.63	1	0.33
Fladen	7	0.59	26.61	0.54	31	0.33	0.64
Firth of Forth	8	0.33	27.36	0.38	26.5	1	0.37
Moray Firth	9	0.73	25.16	0.62	27	0.37	0.33
North Minch	11	0.78	24.18	0.3	24.3	1	0.3
South Minch	12	0.68	24.29	0.32	23.7	1	0.38
Clyde	13	0.4	25.05	0.43	22.8	1	0.33
W Irish Sea	15	0.73	22.88	0.61	25.26	1	0.78

Table 6. Porcupine Bank *Nephrops* estimated Per Recruit Reference Points and associated harvest ratios.

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

Table 7. Porcupine Bank *Nephrops* mean weight in the landings time series.

Year	FU16 Mean Weight in Landings (grammes)
1986	46.5
1987	41.4
1988	49.3
1989	46.4
1990	48.7
1991	44.0
1992	42.8
1993	48.3
1994	46.1
1995	44.8
1996	42.2
1997	40.7
1998	43.2
1999	43.8
2000	60.1
2001	49.6
2002	41.5
2003	57.8
2004	65.3
2005	69.8
2006	76.2
2007	71.1
2008	55.9
2009	53.2
2010	65.3
2011	45.6

Table 8: Summary of correction factors applied to all Functional Units with UWTV surveys.

		Burrows				
Functional Unit	Edge effect	detection	identification	occupancy	Others	*Cum. Bias*
6:Farn Deeps	1.3	0.85	1.05	1		1.2
7:Fladen	1.45	0.9	1	1		1.35
8:Firth of Forth	1.23	0.9	1.05	1		1.18
9:Moray Firth	1.31	0.9	1	1		1.21
11:North Minch	1.38	0.85	1.1	1		1.33
12:South Minch	1.37	0.85	1.1	1		1.32
13:Clyde	1.19	0.75	1.25	1		1.19
15:Irish Sea West	1.24	0.75	1.15	1		1.14
17:Aran	1.35	0.9	1.05	1		1.3
19:South Coast	1.25	0.9	1.15	1		1.3
22:Smalls	1.35	0.9	1.05	1		1.3
16: Porcupine	1.26	0.95	1.05	1		1.26

Table 9: Porcupine Bank *Nephrops* catch options for 2013.

Outlook for 2013

Bias corrected survey index (2012) = 787 million, Mean weights in landings (45.0 g) and retention factors (100%) based negligible discards on observer trips.

Basis	Harvest ratio	Landings 2013 (tonnes)
MSY framework	5.0%	1,771
$F_{0.1}$	5.0%	1,771
$F_{35\%}$	7.7%	2,727
F_{max}	10.5%	3,719

Table 10: Overview of Harvest Ratios for other ICES *Nephrops* stocks

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