Aran, Galway Bay and Slyne Head *Nephrops* Grounds (FU17) 2012 UWTV Survey Report and catch options for 2013

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Abstract

This report provides the main results and findings of the eleventh annual underwater television on the Aran, Galway Bay and Slyne head *Nephrops* grounds, ICES assessment area; Functional Unit 17. The survey was multi-disciplinary in nature collecting UWTV, fishing, CTD and other ecosystem data. The sampling intensity was reduced this year from around 75 stations in the past to 31 on the Aran grounds. A randomised isometric grid design was employed with UWTV stations at 3.5nmi or 6.5km intervals. Previously a 2.25 nmi square grid was used. The kigged burrow abundance estimate declined by 34% relative to 2011 with a CV (or relative standard error) of 5 %. Abundance estimates have fluctuated considerably over the time series but the 2012 abundance is the lowest in the 11 year history of the survey. Four UWTV stations were carried out on the Galway Bay and 3 on the Slyne Head *Nephrops* grounds. Raised abundance estimates for Galway Bay and Slyne Head are provided based on improved knowledge of the boundaries of those areas. *Nephrops* accounted for 85% of the benthic catch by weight from 4 beam trawl tows. The observed length frequency and maturity of female *Nephops* caught was similar to previous years. Various further investigations needed before the next ICES benchmark are discussed.

Key words: *Nephrops norvegicus*, 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 were the sediment is suitable for them to construct their burrows. The *Nephrops* fishery in VII is extremely valuable with landings in 2011 worth around € 70 m at first sale. The *Nephrops* fishery 'at the back of the Aran Islands' can be considered the mainstay of the Ros a Mhíl fleet. Reported landings in 2011 were worth and estimated €3.3 m at first sale. Without this *Nephrops* fishery the majority of vessels in the fleet would cease being economically viable (Meredith, 1999). Given these socio-economic realities good scientific information on stock status and exploitation rates are required to inform sustainable management of this resource.

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). A direct approach of using the UWTV surveys as the basis for catch advice by 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). Since 2009, ICES has provided annual advice for *Nephrops* stocks advice based on UWTV surveys and the methodologies proposed in WKNEPH (ICES 2009a).

This is the eleventh data point in a time series of UWTV surveys on the 'Aran grounds'. The survey covers three geographically discrete mud patches; the Aran Ground, Galway Bay and Slyne Head all of which lie within the ICES assessment area Functional Unit 17 (FU17). The 2012 survey was multi disciplinary in nature; the specific objectives are listed below:

1. To complete randomised fixed isometric survey grid of 31 UWTV with 3.5 nautical mile (Nmi) spacing stations on the "Aran" *Nephrops* ground.
2. To carry out >5 UWTV indicator stations on the Galway Bay and Slyne Head *Nephrops* ground.
3. To obtain 2012 quality assured estimates of *Nephrops* burrow distribution and abundance on the "Aran" *Nephrops* ground (FU17). These will be compared with those collected previously.
4. 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.
5. To collect oceanographic data using a sledge mounted CTD.
6. To sample *Nephrops* and macro benthos using a 4 m beam trawl deployed at ~10 stations.

7. To use the time saved (from reduced grid in FU17 Aran Grounds) to extend the UWTV survey to FU16 Porcupine.

This report details the final UWTV results of the 2012 survey and also documents other data collected during the survey.

Material and methods

From 2002 to 2011 a randomised fixed square grid design has been used for the Aran grounds where a point was picked at random and stations are carried out at a fixed distance north-south and east-west. The distance between stations varied somewhat but was usually 2.25 nautical miles (4.2km). An adaptive approach was taken whereby stations are continued past the known perimeter of the ground until the burrow densities are at or close to zero. SGNEPS (ICES, 2012c) recommended that a CV (or relative standard error) of < 20% is an acceptable precision level for UWTV surveys. Sampling intensity on the Aran grounds was investigated as part of their evaluations (ICES, 2012c). To achieve good spatial coverage over the ground and to generate burrow surface that reflects the underlying abundance the survey design was modified in 2012 to an isometric grid with stations every 3.5Nmi or 6.5km. This randomised isometric grid of 31 stations for FU17 Aran grounds in 2012 was expected to lead to a survey abundance estimate with an RSE below 10% which is well below the SGNEPS recommended limit. The number of stations required reduces by around 50% and time required on the Aran grounds by approximately 40%. The time saved could be used extend survey coverage to other areas within Irish waters such as FU16 Porcupine Banks as also recommended by SGNEPS (ICES, 2012c). The details of the 2012 FU16 UWTV survey are presented in a separate report.

Stations in Galway Bay and Slyne Head were randomly picked from an area defined by previously collected UWTV data, VMS data and multi-beam backscatter data (Figure 1).The boundary use to delineate the edge of the ground was based on information from the fishing industry and has not been changed since 2002.

Survey timing was generally standardised to June each year. In 2003, poor weather and technical problems meant that coverage was poor compared with the other years. In 2004, bad weather prevented the completion of the survey in June so approximately 50% of the stations were carried out one month later in July. In 2003 and 2008 due to weather downtime stations could not be completed at Slyne Head. In 2012 all three *Nephrops* grounds were surveyed successfully during June 5th -14th on RV Celtic Voyager. The protocols used were those reviewed by WKNEPHTV 2007 (ICES, 2007).

At each station the UWTV sledge was deployed and once stable on the seabed a 10 minute tow was recorded onto DVD. 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). In 2012 the USBL navigational data was used to calculate distance over ground for 89% of stations whereas ship data was used for the remaining 11% of stations. In addition CTD profile was logged for the duration of each tow using a Seabird SBE37. This data will be processed later.

Four valid beam trawl tows were conducted randomly across the Aran grounds once TV operations were successfully completed. All *Nephrops* caught were sorted by sex and maturity category, weighed and measured using the NEMESYS electronic measuring system. A length stratified sub-sample of *Nephrops* were taken for each haul. Individual length, whole weight, tail weight, maturity and in the case of males appendix masculina lengths were recorded for each individual. The fish catch was identified to species level sampled by weight (kgs) only. The benthic catch was identified weight (g) and counted. The UWTV station positions and tracks for the four valid beam trawl tows are shown in Figure 1.

No seabed mapping was completed in 2012 as this was not an objective however, Figure 2 shows the updated backscatter image data that has been collected to date on previous surveys (UWTV,INFOMAR surveys) where the dark grey indicates hard ground and the light grey indicates more soft ground.

In line with SGNEPS recommendations all scientists were trained/re-familiarised using training material and validated using reference footage prior to recounting at sea (ICES, 2009b). Figure 3 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 classification key. In addition the numbers of *Nephrops* burrows complexes (multiple burrows in close proximity which appear to be part of a single complex which are only counted once), *Nephrops* activity in and out of burrows were counted by each scientist for each one-minute interval was recorded. Following the recommendation of SGNEPS the time for verified recounts was 7 minutes (ICES, 2009b).

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 OSPAR Special Request (ICES 2011). A key was devised to categorise the densities of seapens based SACFOR abundance scale (Table 1) after ICES (2011). Finally, if there was any time during the one-minute where counting was not possible, due to sediment clouds or other reasons, this 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 (Figure 4). Consistency and bias between individual counters was examined using Figure 5. There were no obvious problems.

The recount data were screened for one minute intervals with any unusually large deviation between recounts. Means of the burrow and *Nephrops* recounts were standardised by dividing by the survey area observed. Either the USBL or estimated sledge lay-back were used to calculate distance over ground of the sledge. The field of view of the camera at the bottom of the screen was estimated at 75cm assuming 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. Occasionally the lasers were not visible at the bottom of the screen due to sinking in very soft mud (the impact of this is

a minor under estimate of densities at stations where this occurred). Figure 6 and Figure 7 shows the variability in density between minutes and operators (counters) for each station. These show that the burrow estimates are fairly consistent between minutes and counters.

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 8.02 for the Aran Grounds. The spatial structure of the density data was studied through variograms. Initially the mid-points of each UWTV transect were converted to UTMs. In addition to the survey stations various boundary positions were included in the analysis. The assumption at these boundary positions was that the *Nephrops* abundance was zero. These stations were outside the known distribution of *Nephrops* or suitable sediment and were approximately equidistant to the spacing within the main grid each year. An unweighted and unsmoothed omnidirectional variogram was constructed with a lag width of approximately 909 and maximum lag distance of between 20-25 km. A model variogram $\gamma(h)$, was produced with a linear component (Equation 1). Model fitting was via the SURFER algorithm using the variogram estimation option. Various other experimental variograms and model setting were examined before the final model choice was made.

Equation 1: Linear Variogram Model

$$\gamma(h) = Co + S \cdot h$$

Where *Co* is the unknown nugget effect and *S* is the unknown slope.
The resulting annual variograms were used to create krigged grid files and the resulting cross-validation data were plotted. If the results looked reasonable then surface plots of the grids were made using a standardised scale. The final part of the process was to limit the calculation to the known extent of the ground using a boundary blanking file. The resulting blanked grid was used to estimate the mean, variance, standard deviation, coefficient of variation, domain area and total burrow abundance estimate.

Although SURFER was used to estimate the burrow abundance this does not provide the krigged estimation variance or CV. This was carried out using the EVA: Estimation VAriance software (Petitgas and Lafont, 1997). The EVA burrow abundance estimates were all extremely close to the Surfer estimate (+- 55 million burrows) with the exception of 2004 when the spatial coverage was poor.

To estimate the abundance for Galway Bay and Slyne Head the area of each ground based on a VMS delimited polygon was calculated in Arcgis10 and an average value used (Table 2). The abundance estimation is the product of the mean density and ground area. The sample variances, standard errors, t-values and 95% CI were calculated for each ground.

Results

A histogram of the observed burrow densities for 2012 and previous years on the Aran Grounds is presented in Figure 8. This shows relatively large inter-annual variation in modal burrow densities. The 2012 modal density was between 0.5 – 0.7 n/m^2. It is was

very noticeable that there was a substantial reduction in density throughout the ground with only one density estimate >0.7/m^2.

The geostatistical structural analysis is shown in the form of variograms in Figure 9. There are a few outliers apparent but they appear have little leverage on the variogram models observed. There is weak evidence of a sill at around 12km in some years but it is not clear and the logarithmic model used does not have a sill. The blanked krigged contour plot and posted point density data are shown in Figure 10. The krigged contours correspond very well to the observed data. The results indicate the densities have fluctuated considerably over the time series and throughout the ground. The fluctuations are not limited to a single station but instead occur fairly homogeneously across the ground. In general the densities are higher towards the western side of the ground rather and there is a notable trend towards lower densities towards the east. On the south western boundary there are indications of high densities close to the boundary. In this area there is a sharp transition from mud to rocky substrate and work is underway to define this boundary more accurately (Figure 2).

The summary statistics from this geo-statistical analysis for the Aran Grounds are given in Table 3 and Figure 11. The 2012 estimate of 423 million burrows is a 34% decrease from 2011. The estimation variance of the survey as calculated by EVA is relatively low (CVs in the order <6%). The 2012 estimate is also 46% below the geometric mean of the series (771 million burrows). The abundance estimates for the Aran Grounds have fluctuated considerably each year to date with a declining trend in recent years. The summary statistics for the indicator stations are given in Table 4. Raised abundance estimates for Galway Bay *Nephrops* ground and for Slyne Head *Nephrops* ground are shown in Figure 11. The Galway Bay mean estimates fluctuate widely but appear to be highly correlated with the Aran ground (except 2004). Estimates for the Slyne Head ground also fluctuate considerably but show no significant correlation with the other areas. The uncertainty bounds for both areas also fluctuate and inter-annual changes are only statistically significant in a few years. On average the Aran Grounds account for ~89% of the total estimated burrow abundance from FU17. Galway Bay and Slyne Head account for 8.6% and 2.7% respectively.

Figure 12 show the standardised length frequency distributions (LFDs) by sex of *Nephrops* caught using a beam trawl on the Aran grounds between 2006 and 2012 surveys. No fishing was carried out on surveys prior to 2006 or in 2008 due to time constraints as a result of poor weather conditions. For plotting purposes the individuals <10mm caught in 2010 were split evenly between males and females as it is not possible to accurately assign sex to individuals that small. The mean lengths for both sexes in the survey have been fairly stable over time around the overall average of 26.66mm. The 2012 results show no signal of recruitment compared to 2011. It should be noted that there is some variability between the sample sizes and structure for individual hauls shown in Figure 13. Carapace lengths in 2012 ranged from 13 mm to 42 mm for one large male.

In 2012 various morphmetric measurements were made during the survey. The estimated length-weight parameters are given in Table 4 together with those currently used in data raising and by ICES for this stock. Bias correction factors for the length-weight conversions are also provided since linear models were fitted to the log CL and log weight data. Male growth was allometric and no significant difference was

observed for the b parameter compared to that currently used for the stock. Female growth is isometric and the estimated b parameter was significantly different ($p>0.01$) that that used by ICES. The female length-weight parameters estimates here give a slightly lower weight-at-lengths for the main lengths in the landings. Using these estimated parameters to calculate landings weights for the raised female 2010 LFD results is a landings estimate which is 1.8% less than was used by ICES for 2010.

The relationship between total weight and tail weight was also investigated using data collected on the survey. The mean conversion factor from tail weight to whole weight was 3.1005with a standard error of 0.0191.

Figure 13 depicts a modelled maturity ogive (binomial GM) for female *Nephrops* where 50% of the females are mature at 23 CL mm. Figure 14 shows the relationship between male carapace length and appendage masculina length (mm). The fitted segmented regression has a break point of 21.90mm CL (see Table).

In 2012 due to time constraints and poor quality of the fish in the catches these were not worked up. A summary of the benthic taxa by tow in presented in Table 7. *Lunatia species* (necklace shell) was the most abundant species and was recorded in all tows. It is also important to note that the mud burrowing shrimp *Calocaris macandrae* was also recorded. The burrow of this species can cause confusion in identification in areas of very soft mud and high densities of *Nephrops* burrows such as the western Irish Sea *Nephrops* ground, but this species is not deemed to be problematic on the Aran Grounds. *Goneplax rhomboids,* a burrowing crab species, was also caught in three of the tows.

The sea-pen presence-absence observations across the *Nephrops* grounds are mapped in Figure 15. All sea-pens were identified from the video footage as *Virgularia mirabilis*. *V.mirabilis* was also present at stations where trawl marks were recorded. This seapen species was recorded as frequently present at 19% and occasionally present at 26% of total stations. Trawl marks were noted at 26% of the Aran stations surveyed with trawl marks present for the entire video transect for 3% of stations. No trawl marks were present at Galway Bay or Slyne Head video transects.

Discussion

In 2012 the survey information up to and including 2011 was used as the main basis for the ICES assessment and advice for the Aran ground (FU 17). ICES concluded that the *Nephrops* stock was fished at a sustainable rate (ICES, 2012 a&b). The 2012 burrow abundance estimates for the Aran grounds have decreased significantly (~34%). Observed burrow densities have fluctuated a lot over time in this area. This is in contrast to the rather stable burrow abundance estimates in FU15 and FU22 (Lordan et al 2011 and Doyle et al. 2011). The 2012 estimate is the lowest in the 11 year history of the survey and is a cause for concern about the sustainability of the stock. Prior to the survey there was a period of very active fishing on the Aran grounds when the industry reported high catch rates of unusually high quality (i.e. large) *Nephrops*. Updating the catch advice for 2013 with this lower 2012 UWTV abundance reduces the catch option at F_{msy} ($=F_{35\%spr}$) from 894 tonnes to 592 tonnes (Table 8).

The survey estimates themselves are very precise notwithstanding the change in design and reduced survey effort in 2012. The fact that the survey abundance in this area tends to fluctuate more than LPUEs has been highlighted in previous survey reports (Lordan et al., 2011). The underlying explanation for high variability could be linked to the survey is seeing variable recruitment alternatively natural mortality may be high and/or variable on this ground.

Analysis of the length frequency distributions LFDs from beam trawl catches may be useful in explaining whether recruitment variability can be linked to fluctuations in UWTV abundance. In the Celtic Sea a clear recruitment signal in the LFDs in 2006 was coincident with higher than average burrow abundance in that year (Doyle, et al. 2012). Unfortunately beam trawl fishing was not carried out around 2003 when the highest burrow abundances were recorded on the Aran grounds. Since 2006 when beam trawl fishing commenced during this survey there hasn't been any clear recruitment signals in the LFDs that might explain inter-annual survey abundance changes. In 2010 very small, recently settled individuals (CL 5-6mm), were caught for the first time. In 2011 a small second mode was apparent at ~17mm CL in the LFDs this is probably that same 2010 cohort. This second mode at 17mm is at the assumed length of burrow formation used in the SCA modelling by ICES (ICES, 2009a).

There are a number of relatively recent improvements in the information base that will need to be incorporated when this stock is next benchmarked in 2013. The multi-beam boundary mapping work (Figure 2), the developing time series of VMS data and UWTV observations will undoubtedly improve the boundary definition for the main Aran ground area. This is expected to scale up the abundance for the Aran ground by at least 10% in most years. This year raised burrow abundance estimates have been calculated for Galway Bay and Slyne Head for the first time. This has mainly been possible due to the developing series of VMS data on the Slyne Grounds and availability of INFOMAR seabed mapping data in Galway Bay. Again this will increase the overall abundance estimate for FU17 by around 10% in most years. For the moment these underestimates in stock abundance are taken into account within the bias correction factor applied for the whole of FU17 advice. This new information will require a revision of this bias correction factor but the relative contribution to landings from the different patches within FU17 should also be investigated.

The collection of length-weight and maturity data are required under the Data Collection Framework (DCF). The morphometric sampling conducted in 2011 and 2012 highlighted some other areas that should be investigated at or before the next benchmark. The length-weight parameters estimated during the survey for females were significantly different from those used currently (ICES, 2012a). This may be a seasonal bias but could have minor implications for the raising of sampling data. The conversion factor from tail weight to whole weight is also somewhat different to that normally used. Around 50% of the landings (in live weight equivalents) from FU17 are usually made as tails but this percentage varies considerably between years (e.g. 2003-2010 range 35-66%). Again this may have some impact on the raising and should be investigated further.

Both male and female maturity information were collected in 2012. The methodology used to assess male maturity was that presented at WKNEPH 2006 (ICES, 2006). The estimated breakpoint for males this year was more similar to the the typical female L_{50}

observed for this stock of around 22-24 mm. The onset of maturity is not particularly relevant to the current assessment and advisory framework although it is something that should be monitored.

Macrobenthos data from the trawl catches was collected for the second time this year. The dominant species by weight was *Nephrops norvegicus* followed by *Lunatia species* (necklace shell) and then *Cancer pagurus* species (edible or brown crab). Overall there is a similar benthic species composition between the tows reflecting the habitat type encountered which is generally sandy mud. *Virgularia mirabilis* were caught by the beam trawl and recorded in 5 tows and this reflects the common occurrence of this species observed on the video footage.

Three other burrowing species: *Goneplax rhomboids* (box crab) and *Calocaris macandrae* (mud burrowing shrimp) were recorded. Of those *Goneplax rhomboids* was the most abundant. The burrows of these species can lead to confusion with *Nephrops* burrows in areas of soft mud and high burrow densities. However, such allocation errors are minimised due to the training procedures employed during the survey. These include refresher training on classical *Nephrops* burrow signatures and consistency verification with reference count analyses (ICES 2008 & 2009b).

An important objective of this UWTV survey is to collect various ancillary information. The occurrence of trawl marks on the footage is notable for two reasons. Firstly, it makes identification of *Nephrops* burrows more difficult as the trawl marks remove some signature features making accurate burrow identification more difficult. Secondly, only occupied *Nephrops* burrows will persist in heavily trawled grounds and it is assumed that each burrow is occupied by one individual *Nephrops* (ICES 2009b). The CTD data collected will be processed at a later stage. This information is relatively easy to collect and over time will augment the knowledge base on habitat and oceanographic regime.

The main objectives of the survey were successfully met for the eleventh successive year. The UWTV coverage and footage quality was excellent throughout the survey. The multi-disciplinary nature of the survey means that the information collected is highly relevant for a number of research and advisory applications.

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References

Campbell, N., Dobby, H., and Bailey, N. 2009. Investigating and mitigating uncertainties in the assessment of Scottish *Nephrops norvegicus* populations using

simulated underwater television data. ICES Journal of Marine Science 66: 646–655. doi: 10.1093/icesjms/fsp046.

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

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

Doyle., J., Lordan, C., Fitzgerald, R., O'Connor, S., Fee, D., Nolan, C. and Hayes, J. 2011. Celtic Sea *Nephrops* Grounds 2011 UWTV Survey Report. Marine Institute UWTV Survey report. http://oar.marine.ie/handle/10793/59/browse?type=title&submit_browse=Title

Gerritsen, H.D. and Lordan C. 2011. Integrating Vessel Monitoring Systems (VMS) data with daily catch data from logbooks to explore the spatial distribution of catch and effort at high resolution. ICES J Mar Sci 68 (1): 245-252.

Petitgas and Lafont, 1997. EVA (Estimation VAriance). A geostatistical software on IBM-PC for structure characterization and variance computation. Version 2.

ICES 2006. Report of the Workshop on Nephrops stocks (WKNEPH). ICES CM: 2006/ACFM: 12 Ref: RMC,FTC,LRC.

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

ICES 2008. Report of the Workshop and training course on Nephrops burrow identification (WKNEPHBID). ICES CM: 2008/LRC: 3 Ref: LRC, ACOM. http://www.ices.dk/reports/LRC/2008/WKNEPHBID/WKNEPHBID2008.pdf

ICES 2009. Report of the Study Group on *Nephrops* Surveys (SGNEPS). ICES CM 2009/LRC: 15. Ref: TGISUR. http://www.ices.dk/reports/SSGESST/2009/SGNEPS/SGNEPS09.pdf

ICES 2009. Report of the Benchmark Workshop on *Nephrops* assessment (WKNEPH). ICES CM: 2009/ACOM:33 http://www.ices.dk/reports/ACOM/2009/WKNEPH/wkneph_2009.pdf

ICES 2010. Report of the Study Group on *Nephrops* Surveys (SGNEPS). ICES CM 2010/SSGESST: 22. Ref: SCICOM, ACOM http://www.ices.dk/reports/SSGESST/2010/sgneps10.pdf

ICES 2011. Report of the ICES Advisory Committee 2011. ICES Advice.2011. Book 1: Introduction, Overviews and Special Requests. Protocols for assessing the status of sea-pen and burrowing megafauna communities, section 1.5.5.3. http://www.ices.dk/committe/acom/comwork/report/2011/Special%20Requests/OSPAR%20Protocols%20for%20assessing%20the%20status.pdf

ICES 2012. Report of the Working Group for Celtic Seas Ecoregion (WGCSE). ICES CM: 2012/ ACOM:12. http://www.ices.dk/reports/ACOM/2012/WGCSE/07.07_Nephrops%20VIIfgh%20FU20_22_2012.pdf

ICES 2012. ACOM advice June 2012, *Nephrops* in Subarea VII, ICES Advice 2012, Book 5, pp 234-283. http://www.ices.dk/committe/acom/comwork/report/2012/2012/Nep-VII.pdf

ICES 2012. Report of the Study Group on *Nephrops* Surveys (SGNEPS). ICES CM 2012/SSGESST: 19. Ref: SCICOM, ACOM http://www.ices.dk/reports/SSGESST/2012/SGNEPS12.pdf

Lordan, C., Doyle, J., Bunn, R., Fee, D. & Allsop, C. "Aran, Galway Bay and Slyne Head *Nephrops* Grounds 2011 UWTV Survey Report", Marine Institute 2011.

http://hdl.handle.net/10793/707

McQuaid, N., Briggs, R.P., Roberts D., 2006. Estimation of the size of onset of sexual maturity in *Nephrops norvegicus* (L.), Fisheries Research, Volume 81, Issue 1, Pages 26-36. http://www.sciencedirect.com/science/article/pii/S0165783606002244

Meredith, D. 2009. The strategic importance of the fishing sector to rural communities and Ireland: a case study of the Rossaveal Region, Co. Galway", Irish Fisheries Investigations No. 4, Marine Institute 1999. http://hdl.handle.net/10793/797

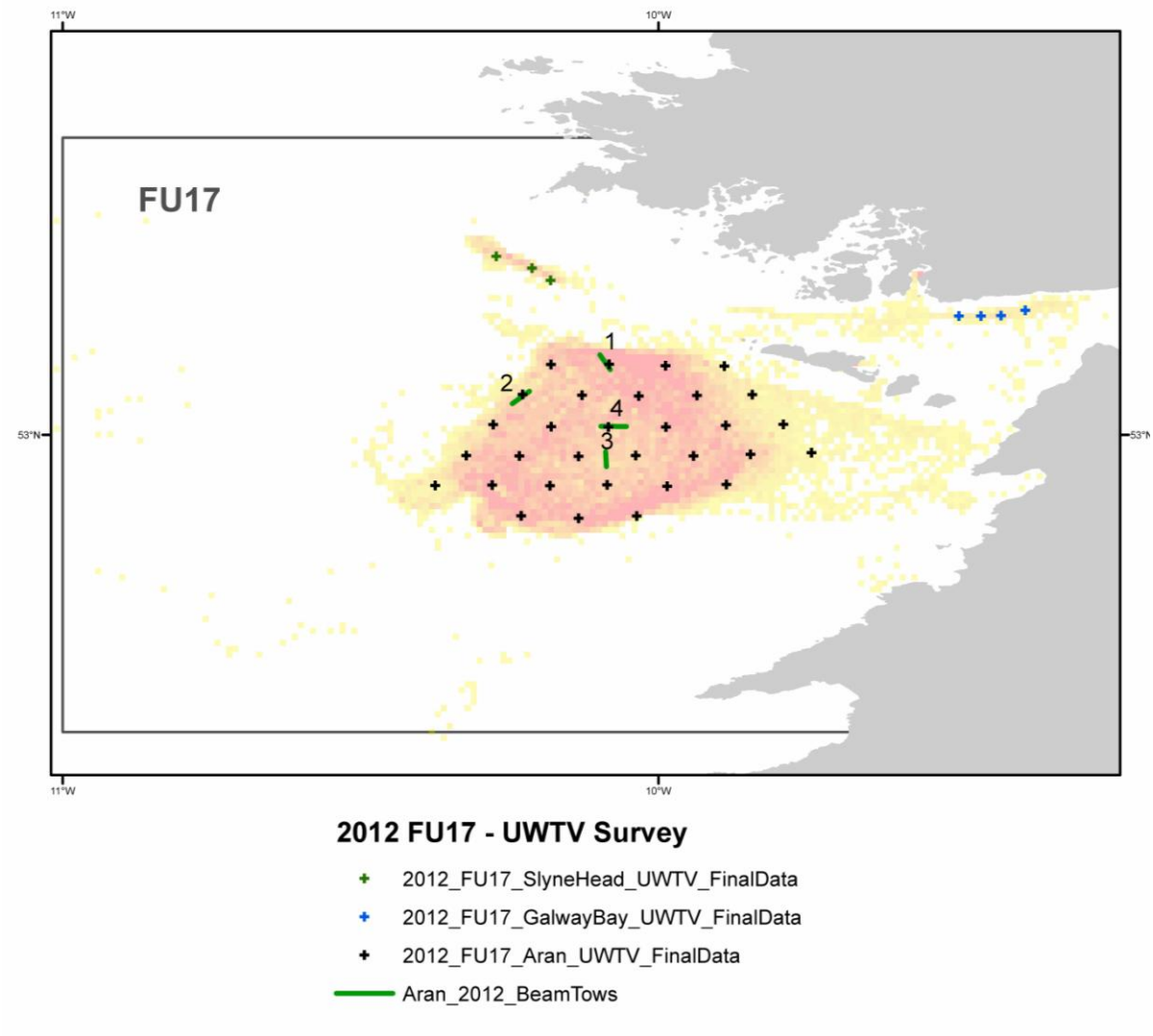

Figure 1: FU17 Aran grounds: UWTV Stations and beam trawl tacks completed in 2012 overlaid on a heat map *Nephrops* directed fishing activity.

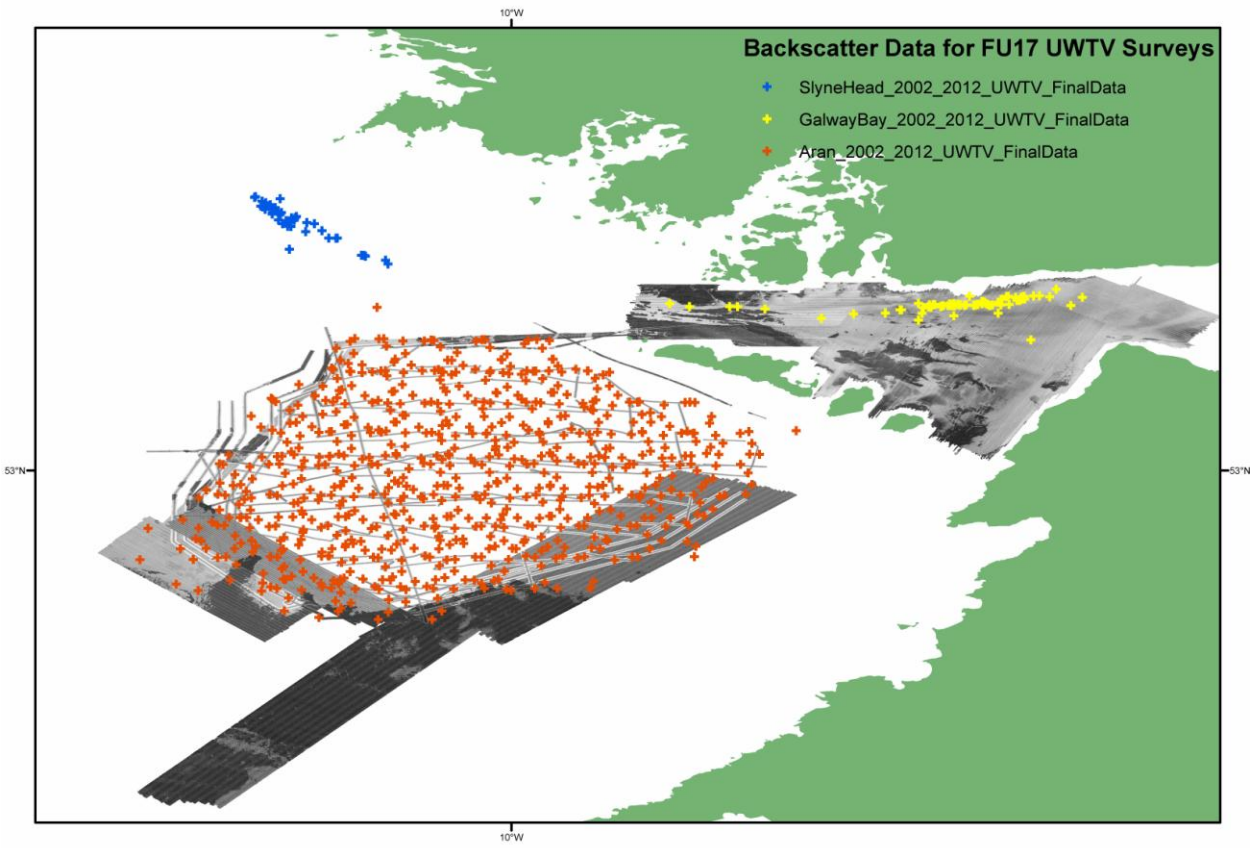

Figure 2: FU17 Aran grounds: Multibeam backscatter data collected to date on the Aran Grounds and Galway Bay (INFOMAR survey).

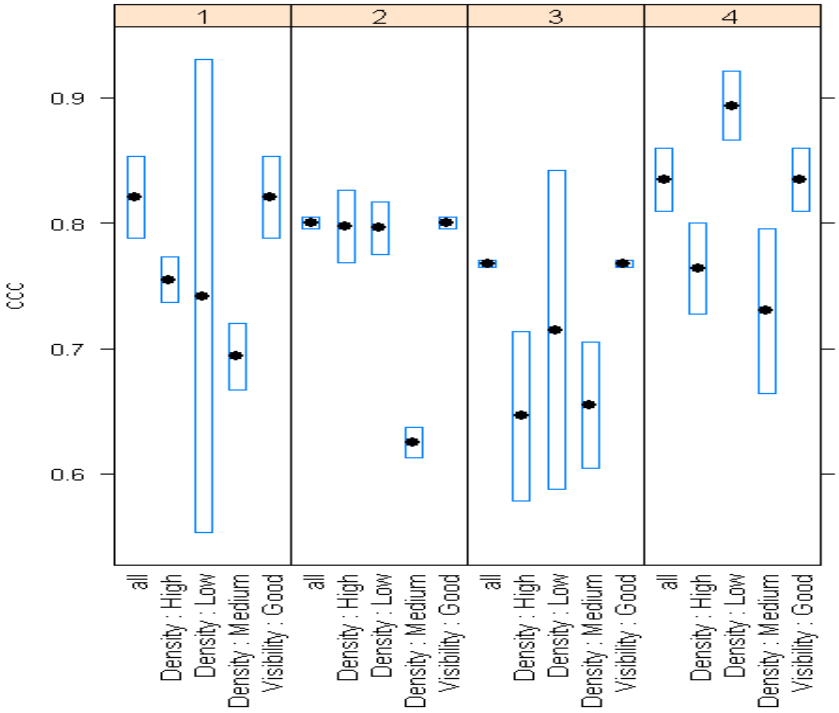

Figure 3: FU17 Aran grounds: 2012 Counting performance against the reference counts as measured by Linn's CCC for FU17 "Aran grounds". Each panel represents an individual. The x-axis (from left to right), all stations pooled, high density, low density, medium density and visibility good.

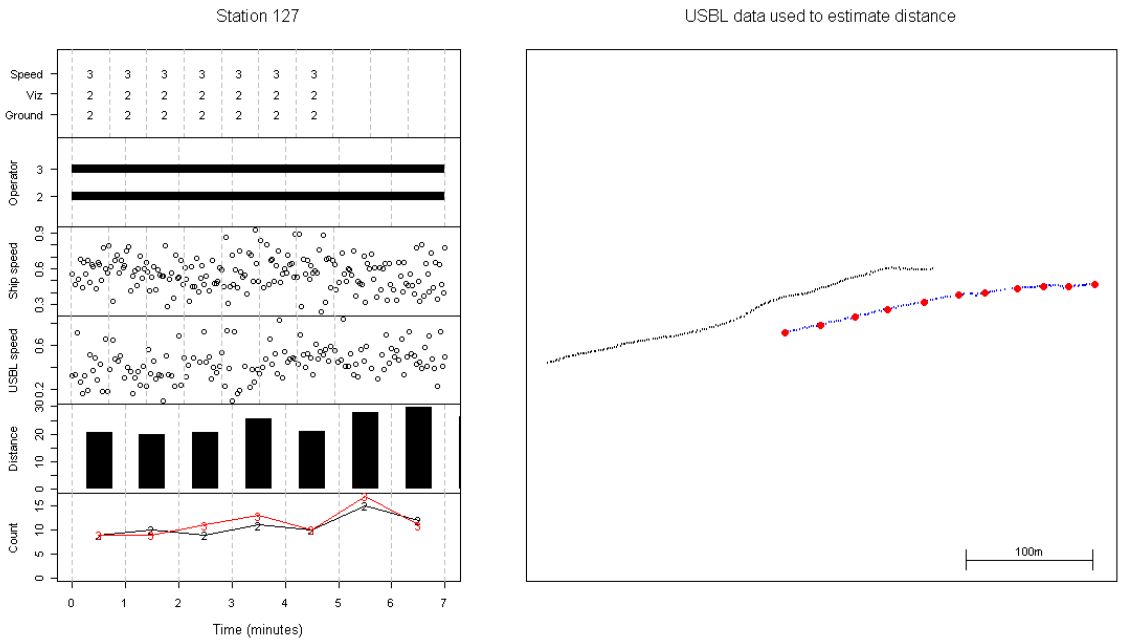

Figure 4 : FU17 Aran grounds: r - tool quality control plot for station127 in 2012.

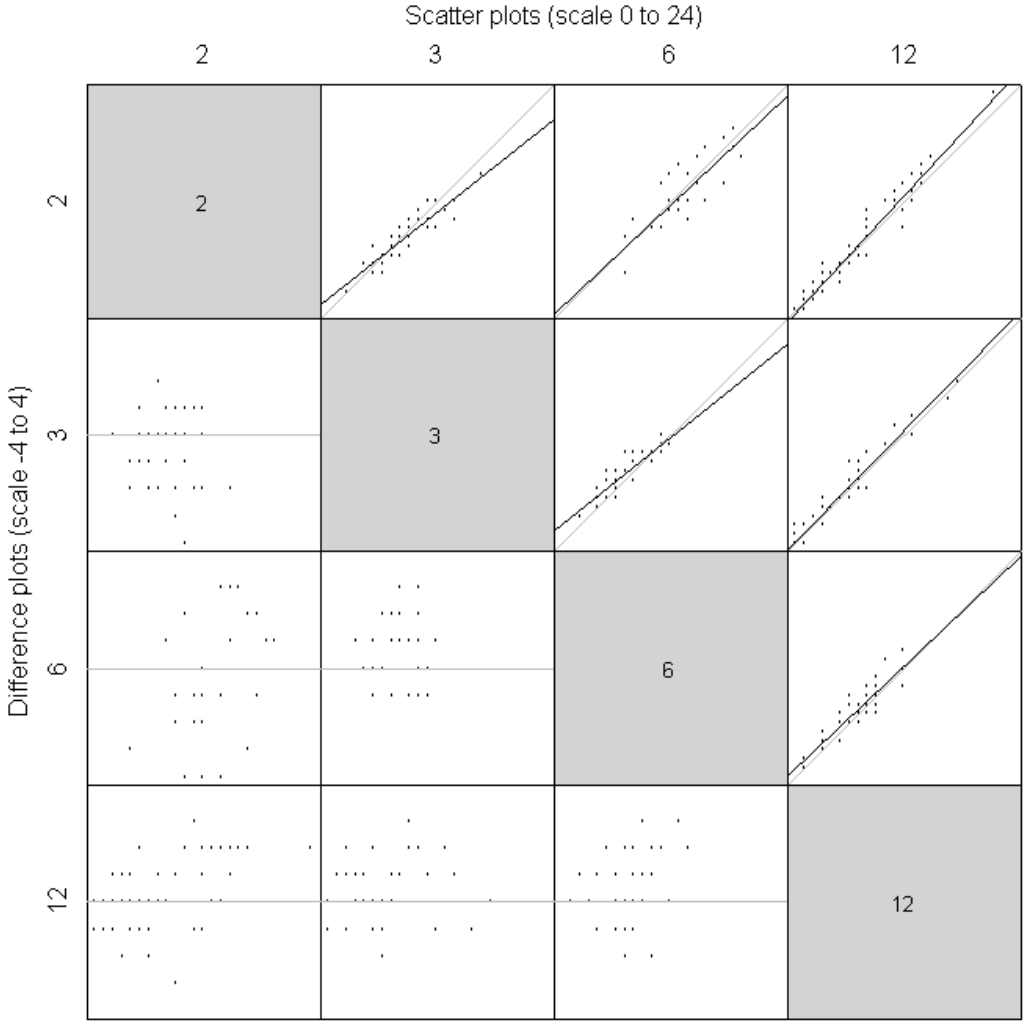

Figure 5: FU17 Aran grounds: Scatter plot analysis of counter correlations for the 2012 survey.

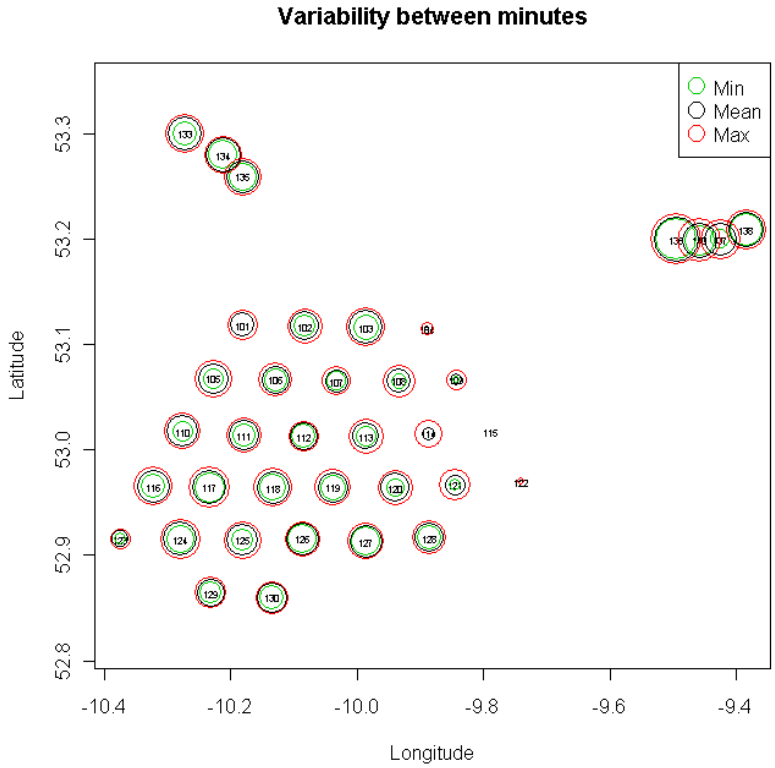

Figure 6 : FU17 Aran grounds: Plot of the variability in density between minutes for each station in 2012.

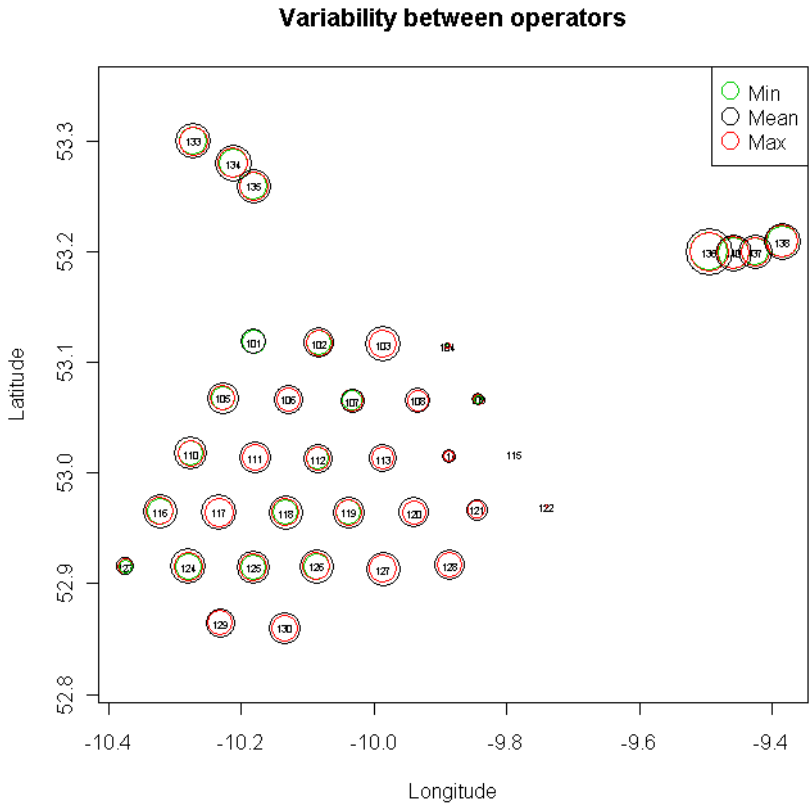

Figure 7 : FU17 Aran grounds: Plot of the variability in density between operators (counters) for each station in 2012.

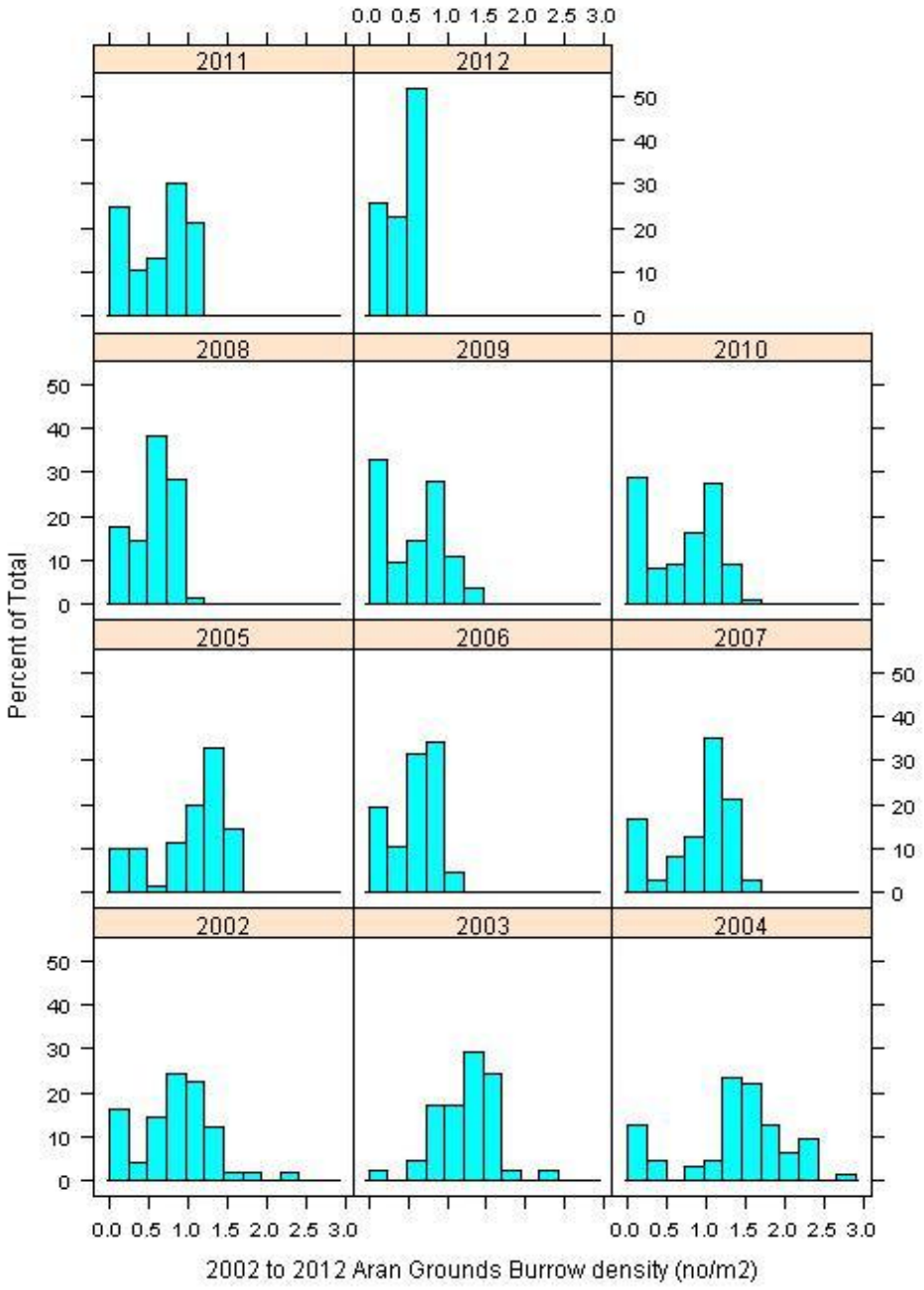

Figure 8: FU17 Aran grounds: Histogram of burrow density distributions by year from 2002-2012.

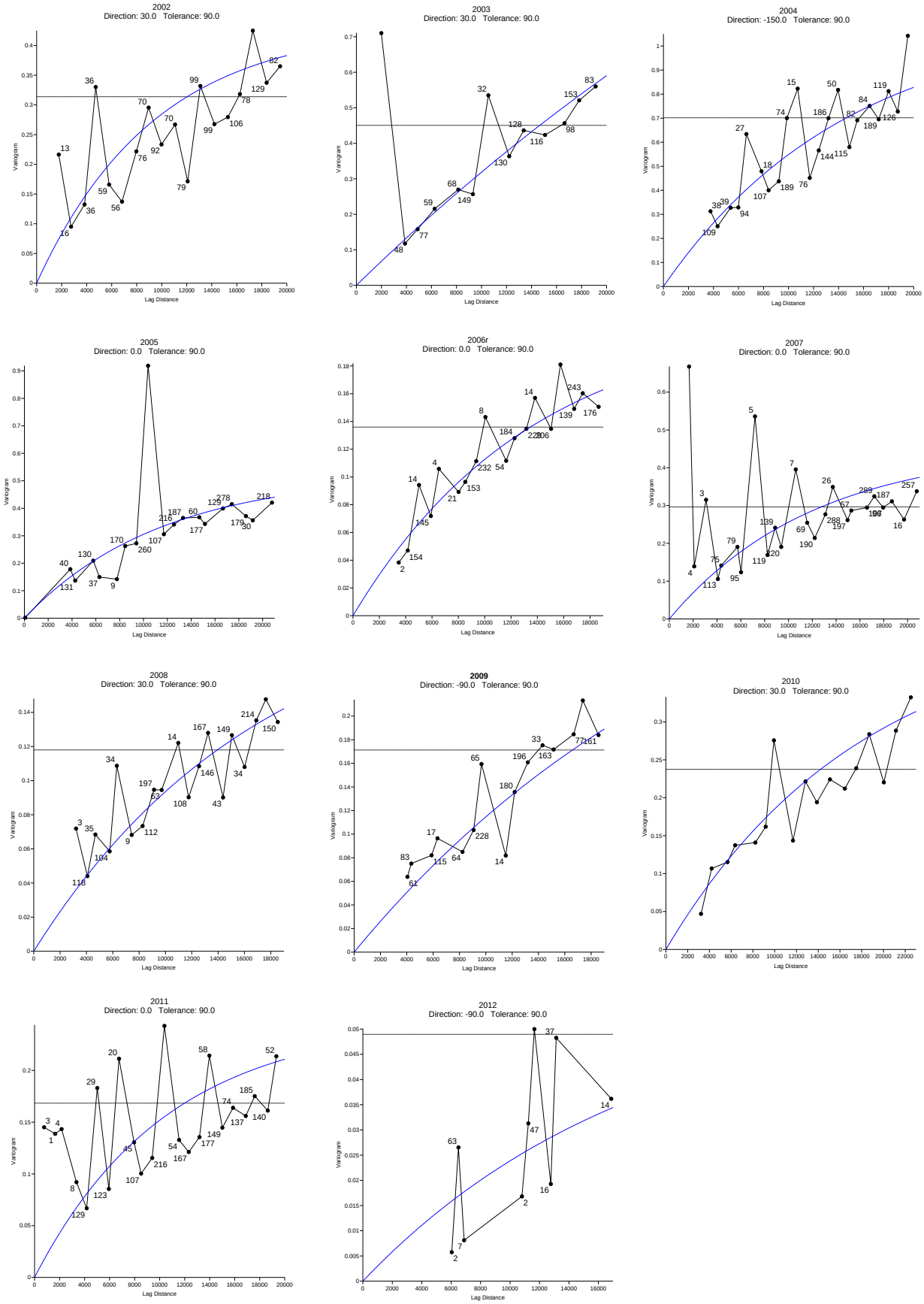

Figure 9: FU17 Aran grounds: Omnidirectional mean variograms by year from 2002-2012.

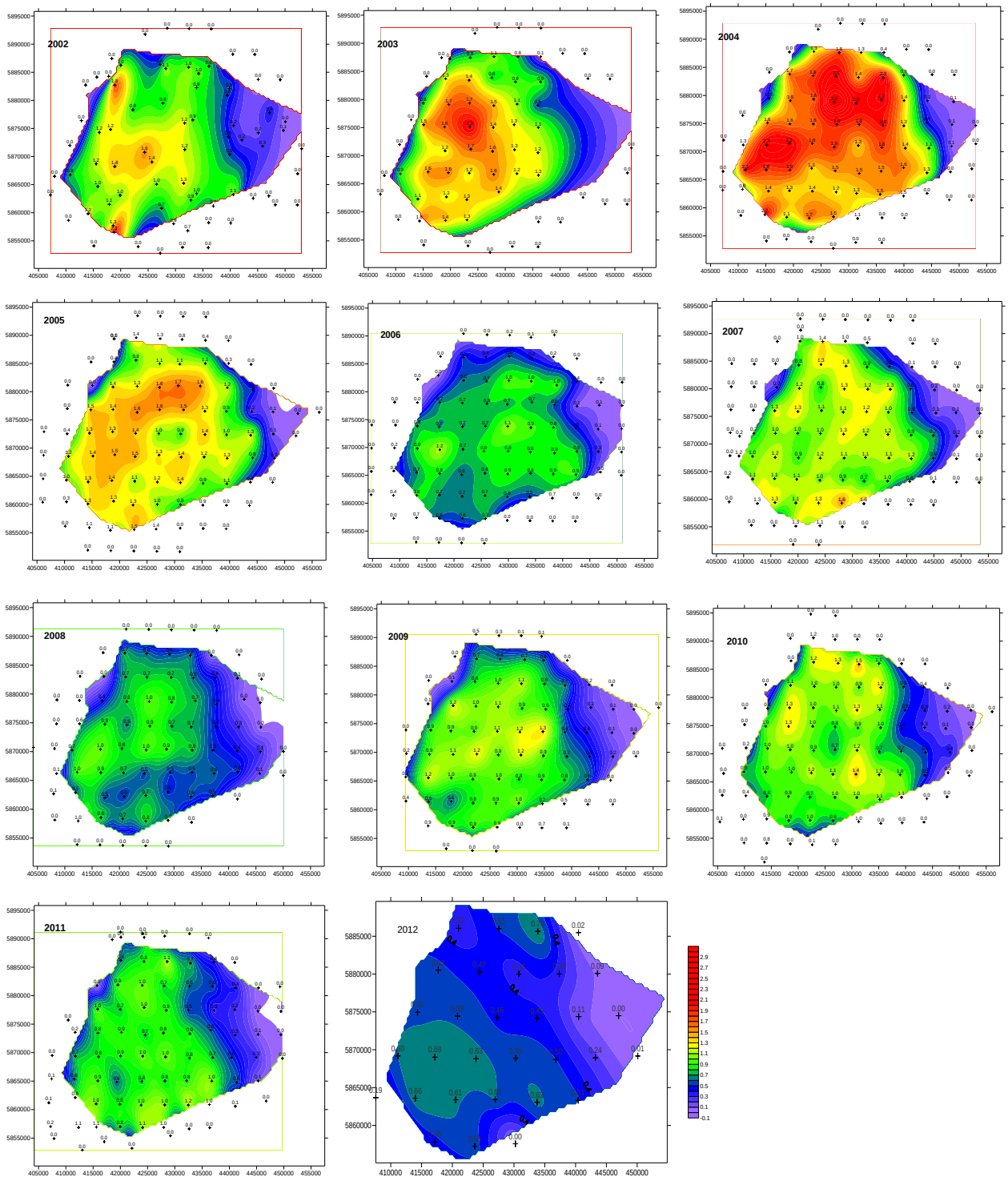

Figure 10: FU17 Aran grounds: Contour plots of the krigged density estimates by year from 2002-2012.

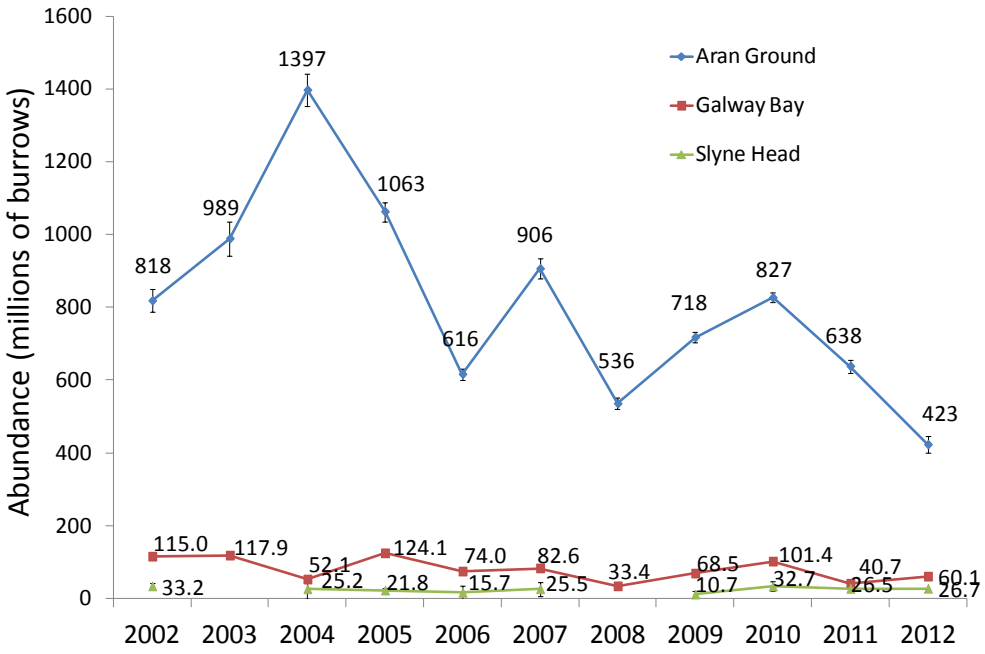

Figure 11: FU17 Aran grounds: Time series of geo-statistical abundance estimates for the Aran Grounds and raised estimates for Galway Bay and Slyne Head 2002-2012 (error bars indicate 95% confidence intervals).

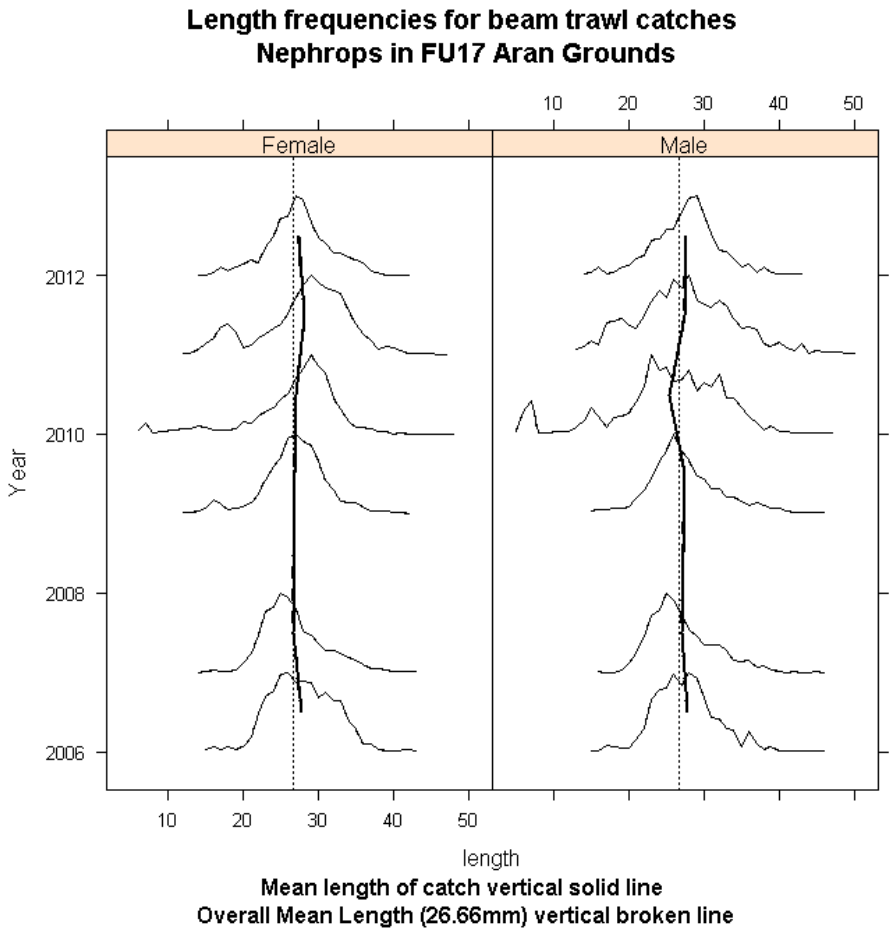

Figure 12: FU17 Aran grounds: Standardised length frequency distributions for male and female *Nephrops* caught using beam trawl during 2006 to 2012 UWTV surveys on the "Aran Grounds" (except 2008).

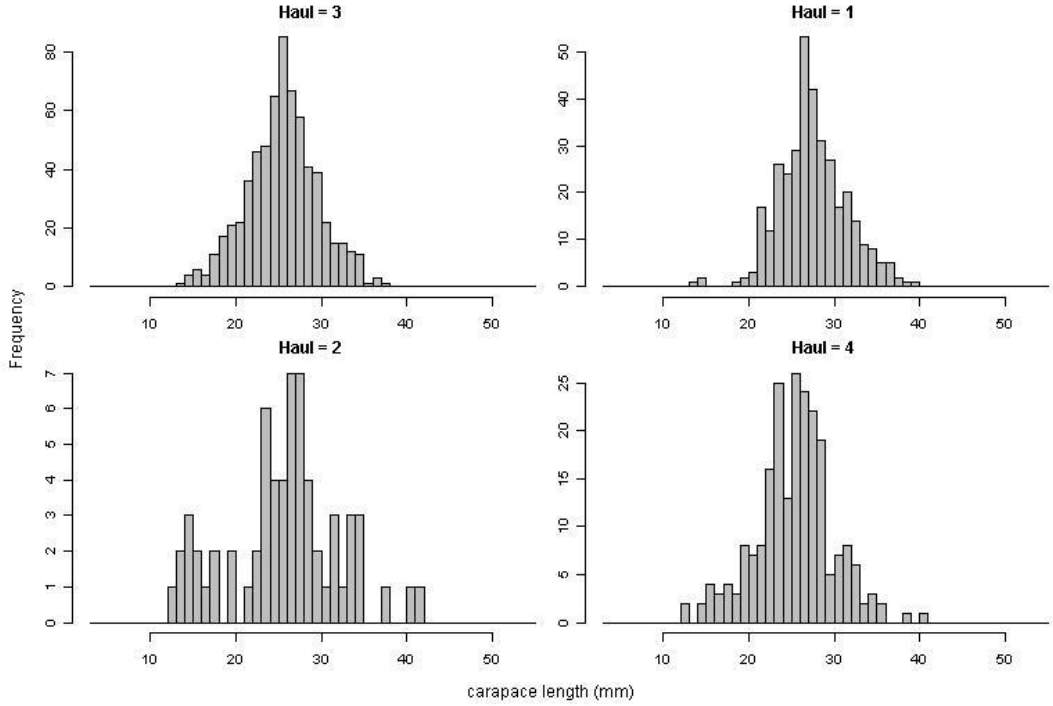

Figure 13: FU17 Aran grounds: 2012 *Nephrops* length frequencies by haul.

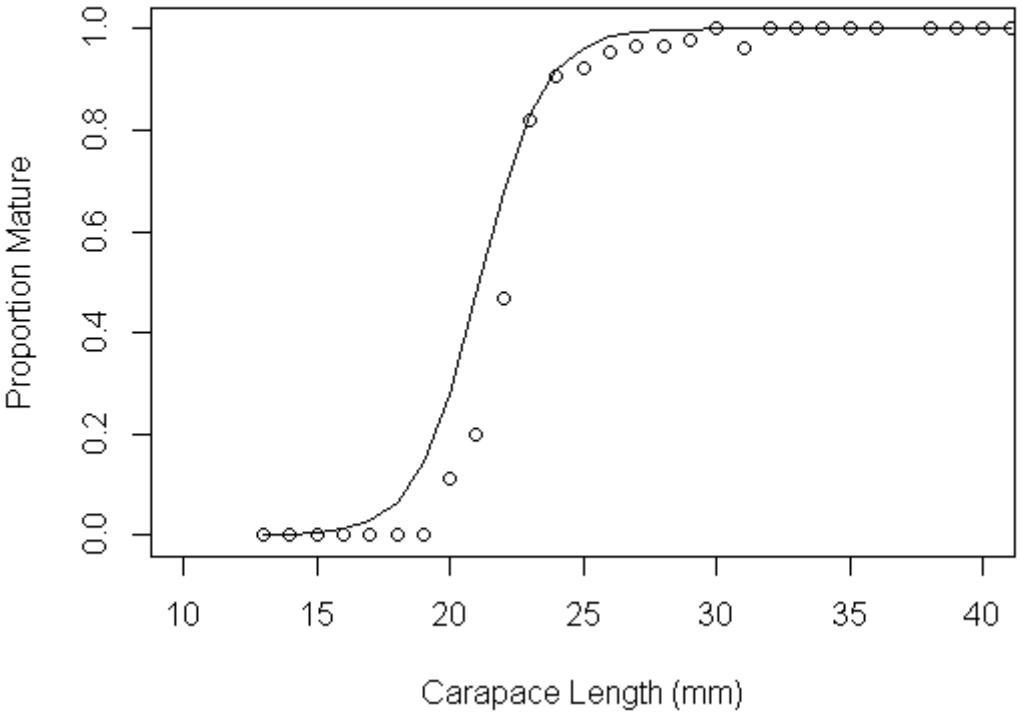

Figure 13: FU17 Aran grounds: Female *Nephrops* maturity ogive based on beam trawl catches in 2012 (L_{50} estimate ~ 23 mm).

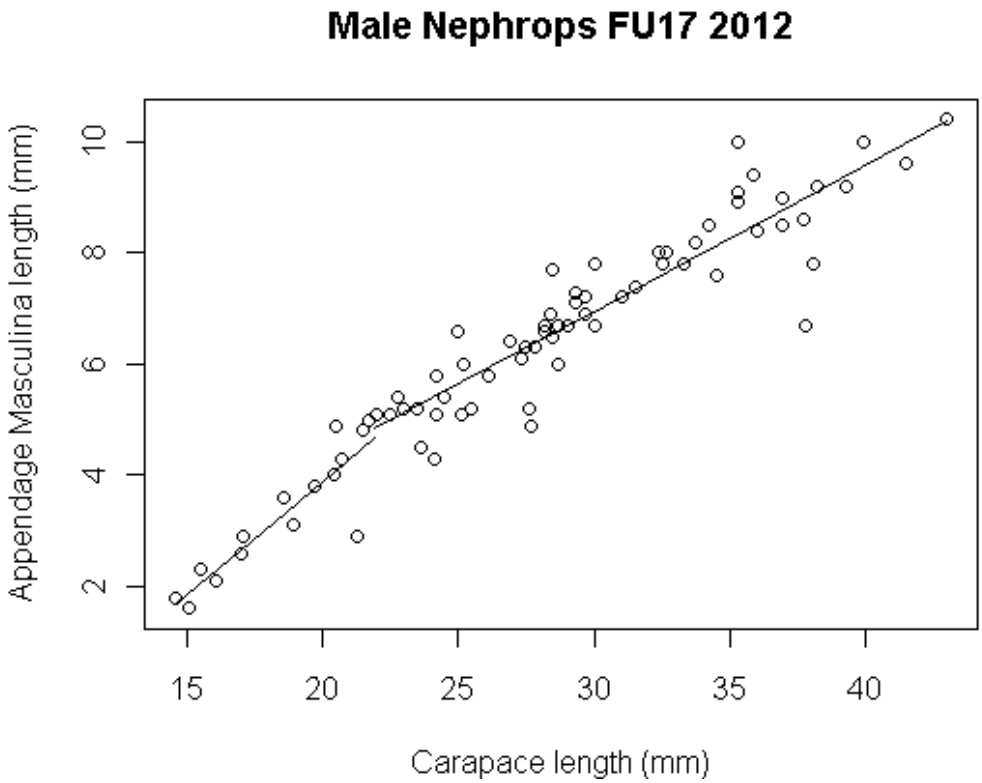

Figure 14: FU17 Aran grounds: Plot of male carapace length and appendage masculina length (mm). The solid line indicates a segmented regression fit to the data with a break point of 21.90 mm CL (see Table 4).

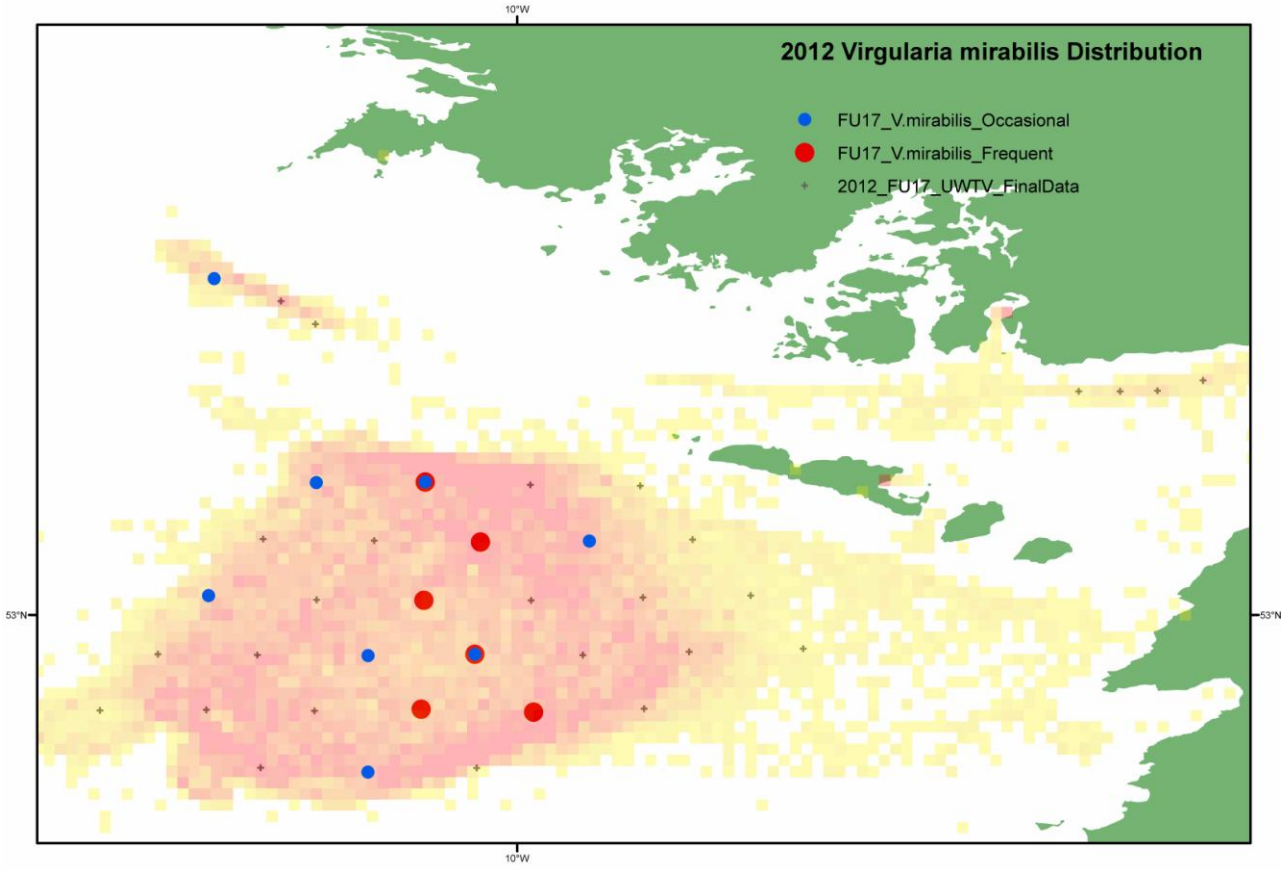

Figure 15: FU17 Aran grounds: Stations where *Virgilaria mirabilis* was identified during 2012 overlaid on a heat map *Nephrops* directed fishing activity.

Table 1: Key for classification of Seapen abundance as used on Irish UWTV surveys.

	Number/Min
Common	20-200
Frequent	2-19
Ocasional	<2

Species
Virgularia mirabilis
Pennatula phosphorea
Funiculina quadrangularis

Sea Pens								
V. mirabilis			*P. phosphorea*			*F. quadrangularis*		
C	F	O	C	F	O	C	F	O

Table 2: FU17 Aran grounds: Area calculations for Galway Bay and Slyne Head *Nephrops* grounds in ArcGIS10.

		ArcGIS Projections			
FU	VMS grounds Polygons	Eckert VI (world) (km2)	Irish National Grid (km2)	Cylindrical Equal Area (km2)	Average (km2)
17	SlyneHead	39.3	39.4	39.3	39.3
17	GalwayBay	74.2	74.0	74.0	74.1

Table 3: FU17 Aran grounds: Overview Aran of geostatistical results from 2002-2012.

FU	Ground	Year	Number of stations	Mean Density (No./m2)	Estimation Standard Deviation	Domain Area (km2)	Geostatistical abundance estimate (millions of Burrows)	CV on Burrow estimate
17	**Aran**	2002	49	0.84	0.04	943	818	4%
		2003	41	1.01	0.06	943	989	5%
		2004	64	1.43	0.05	943	1397	3%
		2005	70	1.09	0.03	936	1063	3%
		2006	67	0.64	0.02	932	616	3%
		2007	71	0.93	0.03	942	906	3%
		2008	63	0.56	0.02	906	536	3%
		2009	82	0.73	0.02	940	718	2%
		2010	91	0.85	0.01	937	827	2%
		2011	76	0.67	0.02	909	638	3%
		2012	*31	0.44	0.02	942	423	5%

* reduced isometric grid 3.5nmi

Table 4 : FU17 Aran grounds: Summary statistics for the Galway Bay and Slyne Head *Nephrops* grounds from 2002-2012.

FU	Ground	Year	Number of stations	Area Surveyed (m^2)	Burrow count	Mean Density (No./m^2)	Var	Standard Deviation	Standard Error	t-value	95%CI	CViid (Relative SE)	Raised abundance estimate (million burrows)
FU17	Galway Bay	2002	7	1,299	2,017	1.58	0.14	0.37	0.14	2.45	0.34	8.8%	115.0
		2003	3	591	941	1.60	0.09	0.29	0.17	4.30	0.73	10.6%	117.9
		2004	9	2,312	1,625	0.73	0.18	0.42	0.14	2.31	0.32	19.4%	52.1
		2005	4	661	1,107	1.67	0.04	0.20	0.10	3.18	0.32	6.0%	124.1
		2006	3	522	522	1.01	0.06	0.25	0.15	4.30	0.63	14.5%	74.0
		2007	5	890	992	1.14	0.06	0.24	0.11	2.78	0.29	9.3%	82.6
		2008	10	1,907	859	0.42	0.10	0.31	0.10	2.26	0.22	23.4%	33.4
		2009	8	1,207	1,116	0.93	0.03	0.16	0.06	2.36	0.14	6.2%	68.5
		2010	10	1,284	1,757	1.61	0.19	0.43	0.14	2.26	0.31	8.6%	101.4
		2011	10	1,355	745	0.51	0.17	0.41	0.13	2.26	0.29	25.2%	40.7
		2012	4	460	374	0.84	0.07	0.27	0.13	3.18	0.43	16.1%	60.1
	Slyne Head	2002	5	1,216	1,027	0.85	0.04	0.19	0.08	2.78	0.23	9.9%	33.2
		2003	-	-	-	-	-	-	-	-		-	
		2004	3	827	531	0.68	0.07	0.27	0.15	4.30	0.66	22.7%	25.2
		2005	3	531	294	0.55	0.00	0.05	0.03	4.30	0.13	5.6%	21.8
		2006	3	526	210	0.41	0.04	0.20	0.11	4.30	0.49	28.1%	15.7
		2007	4	841	547	0.63	0.10	0.31	0.15	3.18	0.49	24.6%	25.5
		2008	-	-	-	-	-	-	-	-		-	
		2009	6	531	144	0.40	0.05	0.22	0.09	2.57	0.23	22.5%	10.7
		2010	9	1,117	928	0.74	0.19	0.43	0.14	2.31	0.33	19.6%	32.7
		2011	7	1,166	785	0.66	0.03	0.18	0.07	2.45	0.17	10.5%	26.5
		2012	3	405	275	0.68	0.00	0.04	0.02	4.30	0.09	3.2%	26.7

Table 5. FU17 Aran grounds: Length-weight parameters by sex estimated for *Nephrops* caught during the 2012 survey together with those currently used to raise the sampling data.

FU	Year	Parameters	Female	Male
		a currently used for FU17	0.000684	0.000322
		b currently used for FU17	2.963	3.207
		a estimated		
		a 2.5% Confidence Intervals	-8.598473	9.116260
		a 97.5% Confidence Interval	-8.032608	-8.328225
		b estimated	3.25671	3.39552
		b 2.5% Confidence Intervals	3.168908	3.276608
		b 97.5% Confidence Interval	3.344515	3.514437
		Bias Correction Factor	1.005876	1.0081058
17	2012	Number of Observations	96	73

Table 6. FU17 Aran grounds: Diagnostics for Regression Model with Segmented Relationship(s) fitted to male CL v's Appendage Masculina.

```
Call:
segmented.glm(obj = m1, seg.Z = ~CL, psi = list(CL = 25))

Estimated Break-Point(s):
   Est. St.Err
21.900  2.195

t value for the gap-variable(s) V:  0.5424765

Meaningful coefficients of the linear terms:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.22366    1.25271  -3.372  0.00122 **
CL           0.40565    0.06686   6.067 5.97e-08 ***
U1.CL       -0.14316    0.06858  -2.087       NA
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for gaussian family taken to be 0.3879967)

Null     deviance: 324.94  on 73  degrees of freedom
Residual deviance:  27.16  on 70  degrees of freedom
AIC: 145.83

Convergence attained in 20 iterations with relative change
0.0006409974
```

Table 7 : FU17 Aran grounds: Summary of benthic catch by tow in weight (kg) and number from 2012 fishing operations.

	Tow1		Tow2		Tow3		Tow4	
Species	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number
Actinuage richardii	0	0	0.098	2	0	0	0	0
Asterias rubens	0	0	0.068	2	0	0	0	0
Astropecten irregularis	0	0	0	0	0.006	1	0.010	1
Buccinum undatum	0	0	0.136	2	0	0	0	0
Calocaris macandrae	**0**	**0**	**0.002**	**1**	**0.004**	**2**	**0**	**0**
Cancer pagurus	0.404	1	0	0	0	0	0	0
Crangon spp	0.218	480	0.066	75	0.034	78	0.048	67
Dichelopandulus bonneri	0.002	2	0.070	36	0.006	2	0.001	1
Eledone cirrhosa	**0**	**0**	0	**0**	**0**	**0**	**0.010**	**1**
Goneplax rhomboides	**0**	**0**	**0.304**	**25**	**0.046**	**7**	**0.008**	**1**
Liocarcinus depurator	0.004	7	0	0	0	0	0.026	4
Liocarcinus holsatus	0.001	1	0	0	0	0	0.002	3
Lunatia spp	0.070	33	0.116	49	0.224	128	0.300	141
Macropodia spp	0.001	1	0	0	0	0	0.001	2
Nephrops norvergicus	**5.290**	**352**	**0.922**	**64**	**7.915**	**651**	**2.624**	**221**
Nucula nucleus	0	0	0.001	2	0	0	0.001	1
Pagurus bernardus	0	0	0	0	0	0	0.014	1
Pagurus spp	0.012	2	0.076	8			0	0
Pontophilus spinosa	0.066	7	0	0	0.008	7	0.008	**8**
Processa spp	0.001	3	0	0	0	0	0.002	1
Rossia macrosoma	0.094	2	0.134	3	0.002	1	0	0
Sepiola spp	0.001	4	0	0	0	0	0.002	3
Stichastrella rosea	0	0	0.002	1	0.002	1	0	0
Virgilaria mirabilis	0.001	4	0.002	5	0	0	0.001	1
Weed	0	0	0	0	0.200	0	0.110	0
Macropipus tuberculatus	0	0	0.020	1	0	0	0	0
Scalpellum scalpellum	0	0	0	0	0.006	1	0	2
Tube Worm casings	0	0	0	0	0	0	0	**2**
Tritonia hombergii	0	0	0	0	0	0	0.001	1
Total	6.165	899	2.017	276	8.453	879	3.169	462

Table 8 : FU17 Aran grounds: Short-term forecast management option table giving catch options for 2013 using the 2012 UWTV estimate.

			Implied fishery	
	Harvest rate	Survey Index (millions)	Retained number (millions)	Landings (tonnes)
MSY framework	10.5%	325	25	592,434
F_{2011}	7.7%	325	18	433,191
$F_{0.1\ Combined}$	7.2%	325	17	406,240
$F_{max\ Combined}$	11.1%	325	27	626,287
	0%	325	0	0
	2%	325	5	112,844
	4%	325	10	225,689
	6%	325	14	338,533
	8%	325	19	451,378
	10%	325	24	564,222
	12%	325	29	677,067

		Basis
Landings Mean Weight (Kg)	0.0235	Sampling 2009-11
Survey Overestimate Bias	1.30	WKNEPH 2009
Survey Numbers (Millions)	423	UWTV Survey 2012
Prop. Retained by the Fishery	0.74	Sampling 2009-11