Western Irish Sea *Nephrops* Grounds (FU15) 2018 UWTV Survey Report and catch options for 2019

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Abstract
This report provides the main results and findings of the 16th annual underwater television survey on the 'Irish sea west *Nephrops* grounds' ICES assessment area, Functional Unit 15. The survey was multi-disciplinary in nature collecting UWTV and other ecosystem data. The 2018 design consisted of a randomised isometric grid of 100 stations at 4.5 nautical mile intervals out over the full known extent the stock. The resulting krigged burrow abundance estimate was 4.9 billion burrows. This was a similar result of that obtained in 2011, and 9% lower than the abundance in 2017. In contrast to 2017 the spatial distribution of burrows appears more homogenous across the survey area, with high densities in the SW of the ground in shallower water, and higher densities in the NW of the ground in deep water. Overall densities are high and abundance remains stable, well above MSY $B_{trigger}$. Reducing the number of stations compared to 2011 has not affected the accuracy of the survey estimate to date. The CV (or relative standard error) of 3% is in line with previous estimates and well below the upper limit of 20% recommended by SGNEPS 2012. Total catches and landings options at various different fishing mortalities were calculated and fishing at F_{msy} in 2018 implies a total catch option at F_{msy} (=F_{max}) of 11,107 tonnes which results in landings of no more than 8,959 tonnes. The sea-pen species observed in 2018 was predominantly *Virgularia mirabilis,* with one potential observation of *Pennatula phosphorea* (which requires verification). Sea-pens were observed at 20% of stations with high densities observed in the south-west of the ground. Trawl marks were noted at 26% of the UWTV stations.

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

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Introduction

The Norway lobster, *Nephrops norvegicus*, is exploited throughout its geographic range, from Icelandic waters to the Mediterranean and the Moroccan coast. The western Irish Sea stock (FU15) is by far the most productive of all the *Nephrops* stocks currently fished yielding landings of 7,000-10,000 tonnes annually from a relatively small geographic area (ICES, 2012a). *Nephrops* spend a great deal of time in their burrows and their emergence behaviour is influenced by several factors: time of year, light intensity, tidal strength, etc. Underwater television surveys and assessment methodologies have been developed to provide a fishery independent estimate of stock size, exploitation status and catch advice (ICES, 2009a & 2012a).

This is the 16th survey in a time series of UWTV surveys in the western Irish Sea carried out jointly by the Agri-Food and Biosciences Institute (AFBI), Northern Ireland, and the Marine Institute, Ireland. The 2018 survey was multi-disciplinary in nature; the specific objectives are listed below:

1. To complete randomised fixed isometric survey grid of 100 UWTV with 4.5 nautical mile (nM) spacing stations on the western Irish Sea *Nephrops* ground (FU15).
2. To obtain 2018 quality assured estimates of *Nephrops* burrow distribution and abundance on the western Irish Sea *Nephrops* ground (FU15). These will be compared with those collected previously.
3. To collect ancillary information from the UWTV footage at each station such as the occurrence of sea-pens, other macro-benthos and fish species and trawl marks on the seabed.
4. Technology, staff and protocol transfer between AFBI, the Marine Institute and Cefas.

This report details the final UWTV results of the 2018 survey and also documents other data collected during the survey.

SGNEPS (ICES, 2012b) recommended that a CV (or relative standard error) of < 20% is an acceptable precision level for UWTV surveys. SGNEPS also recommended that investigations into the precision of surveys be carried out and where possible survey effort should be extended to grounds not already covered with UWTV surveys (including FU16, FU19 and FU20-21).

Material and methods

From 2003 to 2018 a randomized fixed square grid for the western Irish Sea (FU15) Nephrops ground has been used. An adaptive approach is taken whereby stations are continued past the known perimeter of the ground until the burrow densities are zero or very close to zero. The initial ground perimeter has been established using a combination of integrated logbook-VMS data (using the methods described in Gerritsen and Lordan, 2011), British Geological Survey (BGS) and other sediment maps, and previously collected UWTV data. The same ground boundaries have been used throughout the time-series. The grid spacing from 2003 to 2011 was 3.5 nautical miles (nM). Following a review (Doyle *et al.*, 2013) the grid design was changed from a 3.5 nM to 4.5 nM in 2012. In 2013, the grid spacing was increased further to a 5.0 nM isometric grid, whereas a 4.5 nM isometric grid was used again in 2014 - 2018 to ensure all edge of ground areas were represented adequately.

The survey took place on RV *Corystes* between 30th July and 9th August 2018. The survey covered the western Irish Sea (FU15) grid and the eastern Irish Sea (FU14). The results for FU14 will be presented in a separate report, led by Cefas. Survey timing for FU15 was generally standardised to August each year and was also timed to take full advantage of the neap tides when underwater visibility is normally better.

The protocols used were those presented and reviewed by WKNEPHTV 2007 (ICES, 2007) and are 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. Vessel position (dGPS) were recorded every 1 second. The navigational data were quality controlled using an "R" script developed by the Marine Institute (ICES, 2009b). In 2018 due to technical issues with the USBL, ship dGPS navigational data were used to calculate distance over ground for 100% of stations.

No sediment sampling was carried out in 2018 as the Irish Sea is well sampled through various research programmes and good sediment maps exist for this area.

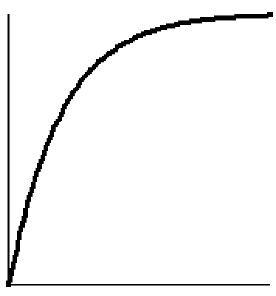
In line with SGNEPS recommendations all scientists were trained/re-familiarised using training material and validated using reference footage prior to recounting at sea (ICES, 2009b). Figure 1 shows individual's counting performance in 2018 against the reference counts as measured by Lin's concordance correlation coefficient (CCC). A threshold of 0.5 was used to identify counters who needed further training. One scientist (counter "4" in Figure 1) was unable to count to the repeatability required following further training, and therefore did not participate in counting during this survey. 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 and recorded by each scientist for each one-minute interval. Following the SISP (Series of ICES Survey Protocols) agreed by WGNEPS 2016 (ICES, 2016), eight minutes of recounts should be carried out for each station although only the first minute is then excluded from analysis with only seven minutes used for analysis. The first minute is thus treated as a 're-familiarisation' minute.

Notes were also recorded each minute on the occurrence of trawl marks, fish species and other species. Semi-quantitative abundance of seapen species were also recorded according to OSPAR Special Request (ICES 2011). A key was devised to categorise the densities of sea pens based on SACFOR abundance scale (Table 2) 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), the duration was also recorded 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 (examples are given in Figures 2 and 3). Consistency and bias between individual counters were examined using a scatter plot matrix (not shown). There is some variability, but no obvious bias problems between counters.

The recount data were subjected to Lin's concordance correlation coefficient (CCC) for each station, and where the statistic fell below a threshold of 0.5, a third independent trained counter completed an additional set of recounts. These recounts were checked again using Lin's CCC and if the statistic remained below the threshold of 0.5, a fourth independent count was completed. If yet again the statistic remained below the threshold of 0.5, a consensus count was completed by the four counters who had previously counted the footage. This application of Lin's CCC to recount data during the survey is the third year where this has been used to bring quality control in line with other laboratories' protocols, such as those of Marine Scotland, Marine Institute and Cefas. The "R" scripts were developed by AFBI based on those used by Cefas (courtesy of Ana Leocadio). Lin's CCC was only applied to stations where average count per minute exceeded 1.5 burrow systems. In total, 35 of the stations failed to meet the 0.5 Lin's CCC threshold based on their first two counts by independent counters. Following third counts over 82% stations successfully met these threshold, however 7 stations did not pass after having 4 counts by independent staff and a consensus count was carried out for each of these stations.

Arithmetic means of the burrow density and *Nephrops* recounts were standardised by dividing by the survey area observed. The ship's navigation data 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 74cm using lasers with the sledge flat on the seabed (i.e. no sinking).

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 11. The spatial structure of the density data were studied through variograms. The mid-points of each UWTV transect were converted from a geographical data projection (WGS 1984 datum) to the Universal Transverse Mercator projected coordinate system (UTM). No additional stations were added with assumed zero density outside the known distribution of *Nephrops* or suitable sediment in the krigging process. An un-weighted and un-smoothed omni-directional variogram was constructed with a lag width of 2000m and maximum lag distance of 50 km. A model variogram $\gamma(h)$ was produced with an exponential model (see below). Model fitting was via the SURFER algorithm using the variogram estimation option. Various other experimental variograms and model settings were examined before the final model choice was made.



Exponential Model
Cressie (1991, p. 61)

$$\gamma(h) = C\left[1 - e^{-h}\right]$$

The resulting annual variograms were used to create krigged grid files. Surface plots of the grids were then produced 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, with this blanking file being the same as used in all previous survey years. The resulting blanked grid was used to estimate the domain area and total burrow abundance.

Although SURFER was used to estimate the burrow abundance, this does not provide the krigged estimation variance or Coefficient of Variance (CV). Furthermore, a number of laboratories have moved to using "R" Geostats package to complete the interpolation and analysis of data, and to calculate the CV. Example "R" code was provided by the Marine Institute and trialled on the FU15 2016 data, using the adjusted burrow densities. A historical comparison of SURFER based estimates and R-geostats estimates are presented in Table 3. Consistent trend agreement was observed between the Surfer based estimate and R-Geostats, however, with a positive bias (mean = .23). The Coefficient of Variance is provided using R-Geostats for the 2018 dataset.

Results

The station positions are shown in Figure 4. A violin plot of the observed burrow densities from 2003 to 2018 on the western Irish Sea is presented in Figure 5. Over the time series available the density estimates observed are very similar with average density of around 1 burrow/m^2. Figure 6 and Figure 7 show the variability in density between minutes and operators (counters) for each station, respectively. These quality control and consistency plots show that the burrow estimates were fairly consistent between minutes and counters. Variability is higher between minutes than counters. Higher density stations showed the greatest variability between counters. Stations in the west and south-west of the ground tend to show higher minute by minute variability than those in the centre and to the north of the ground. Recent trawling activity and the co-occurrence of other burrowing species (e.g. *Goneplax rhomboides* and *Calocaris macandreae*) sometimes impacts on the between minute variability.

The geo-statistical structural analysis is shown in the form of variograms in Figure 8. There is a weak evidence of a sill in some years. The blanked and krigged contour plot and posted point density data are shown in Figures 9 - 11. The krigged contours correspond well to the observed data. These densities surfaces show a relatively dynamic situation. Some parts of the ground have consistently higher or lower densities, such as to the south-west of the ground, near the northern-most extent of the ground, with a further 'hot spot' to the east of the ground (southwest of the Isle of Man). In most areas densities drop to zero or near zero as the ground boundary is approached, with the exception in 2016 - 2018 (and to a lesser extent in 2014) across the widest part of the ground at the western and easten (immediately SW of Isle of Man) boundaries. There tends to be a lower density towards the centre of the ground. The 2018 spatial pattern is most similar to that in 2012, but with slighty lower densities observed towards the southern end of the ground. The high density areas observed in the FU15 in the past had almost disappeared in recent years, however 2016 and 2017 has exhibited some stations with an average burrow density of greater than 2 systems/m^2; but in 2018 there were no densities this high observed, with the densities similar to those observed in 2009 (see Figure 5).

The summary statistics from this geo-statistical analysis are given in Table 3 and plotted in Figure 12. The 2018 final adjusted abundance estimate of 4.9 billion burrows is very close to that estimated in 2011 (Doyle et al., 2013). The overall burrow abundance trend is fairly stable although the abundance did decline between 2005 and 2008, and some decline was also seen between 2012 and 2015 but increased in 2016, and again in 2017, before falling in 2018. The CV for 2018 was 3% indicating a very precise survey in line with CVs observed previously.

Seapen distribution across the western Irish Sea *Nephrops* grounds is mapped in Figure 13. The majority of seapens were identified from the video footage as *Virgularia mirabilis*, with one potential observation of *Pennatula phosphorea* (which requires validation). Trawl marks were noted at 26% of the stations surveyed, which is an descrease of 10% to that observed in the previous survey year.

Discussion

The western Irish Sea (FU 15) stock has accounted for >40% of the total landings reported to WGCSE for ICES Sub-area VII (ICES, 2018) making it singly the most important FU in the TAC management area. The burrow densities typically observed in FU15 are amongst the highest observed of all *Nephrops* stocks but the mean sizes of individuals in the catches are relatively small. It appears that growth is suppressed due to competition and/or recruitment effects (Johnson et. al, 2012). Despite the smaller size of individuals, the fishery is particularly important to the Northern Irish and Irish *Nephrops* métiers. In the last decade it has become by far the most economically important fishery in the Irish Sea. The Western Irish Sea *Nephrops* stock is relatively well studied with size information on catches extending back to the 1970s, a trawl survey series since 1994 and larval production surveys in a few years.

Since the benchmark assessment by ICES in 2009 this UWTV survey has become the main input for assessment and calculation of catch options for this stock. The survey information up to 2012 was used as the main basis for the ICES assessment of status and exploitation rate up to 2012. ICES concluded that this stock abundance is stable and is above MSY $B_{trigger}$ (ICES, 2013). The 2018 abundance estimate remains well above the MSY $B_{trigger}$ (biomass trigger) proposed by ICES of 3.0 billion burrows which was derived from a longer time series of trawl survey data. All other stock status indicators suggest that the stock remains at a stable healthy condition (ICES, 2013). Table 4 is an updated management option table giving total catch and landings options at various levels of fishing mortality for 2019. Using the 2018 estimate of abundance would imply a total catch option at F_{MSY} ($=F_{max}$) of 11,107 tonnes which results in landings of no more than 8,959 tonnes.

SGNEPS 2012 recommended a review of survey sampling intensity (ICES, 2012b). Following a review (Doyle et al., 2013) the grid design was changed from a 3.5 nautical mile square grid prior to 2012 to 5.0 nautical mile isometric grid in 2013. In 2014 the grid spacing was reduced to 4.5 nautical mile isometric grid as in 2012, and has remained at this spacing in the following years. The precision for all surveys at 4.5 nM spacing appears stable and high, with a CV of 3% which is in line with previous estimates well below the SGNEPS 2012 recommendation of 20%.

Burrow identification in the western Irish Sea is, at times, difficult due to the high underlying burrow densities and sometimes poor visibility. The burrows of *Calocaris macandreae* (a mud burrowing shrimp species) are abundant particularly in the softer muds in the middle of the western Irish Sea grounds, and the burrows of the crab *Goneplax rhomboides* in the west and south-west in particular cause some difficulty with *Nephrops* burrow discrimination. 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). The counting performance of the 2018 counters was generally very high with Lin's CCC scores >0.5 for all stations.

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 can 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, 2009a). The CTD data collected will be processed at a later stage. This information is relatively easy to collect and over time will provide a useful data series on oceanographic regime in this region.

The impact of trawling activity on the seabed communities' structure and functioning has been raised a potential ecosystem concern (OSPAR, 2010). Seapens in particular have been identified as a potential indicator species for benthic habitat health status. OSPAR have sought advice from ICES on the utility of UWTV surveys for collecting data on seapen status and distributions (ICES, 2011). The occurrence of seapens has been noted on this survey since the outset. This is the sixth year that a systematic quantification and identification of seapens to species level was undertaken. *Virgularia mirabilis* was positively identified on the 2018 footage with potentially also footage at one station of *Pennatula phosphorea* , which has not been observed in over five years. There is evidence of co-occurrence of trawl marks and seapens, particularly in the south of the ground.

The main objectives of the survey were successfully met for the 16th successive year. The UWTV coverage and footage quality were generally good on the western Irish Sea grounds due to survey timing. Due to fishing activity over some stations these sites had to be re-visited as first attempts were marred by poor visibility. There were some technical difficulties with camera equipment, notably the camera cable which required replacement twice and involved visiting port half way through the survey. This resulted in 36h down time due to transit time involved to port and repairs required. Adverse weather conditions (Force 8 southerly) prevented camera operations for a futher 8h in total over 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.

Acknowledgments

We would like to express our thanks and gratitude to the Captain and crew of RV *Corystes* for their good will and professionalism during the survey. Finally, thanks to the AFBI, Marine Institute, and CEFAS staff onboard for their hard work and enthusiasm in making this survey a success.

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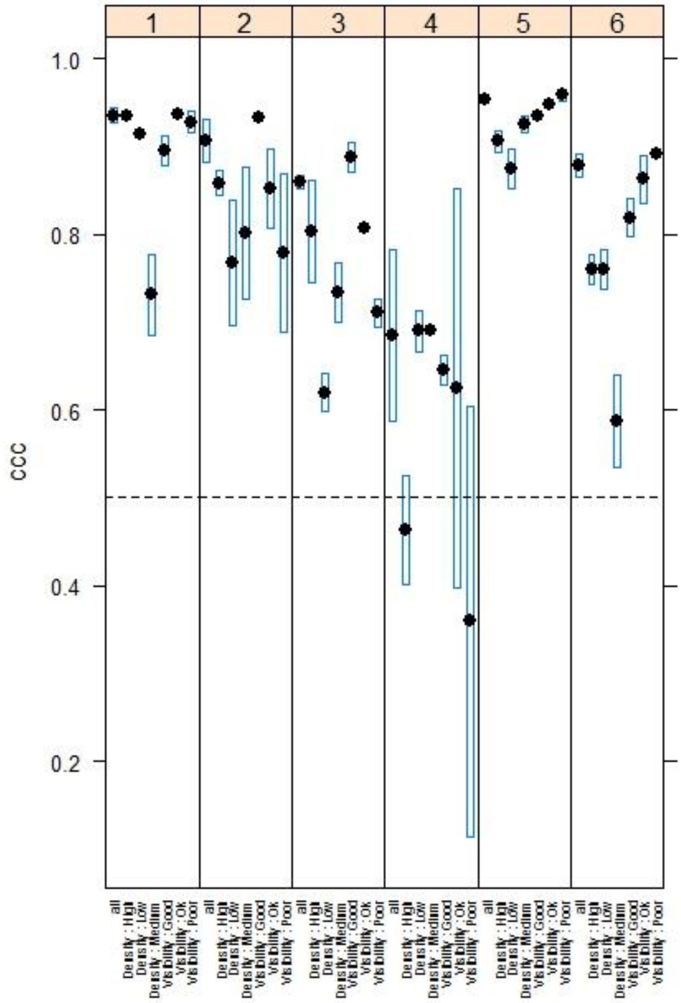


Figure 1: FU15 western Irish Sea grounds: 2018 count performance against the reference counts as measured by Linn's CCC for FU15 reference set. Each panel represents an individual. The x-axis (from left to right) shows all stations pooled, high density, low density, medium density and visibility good.

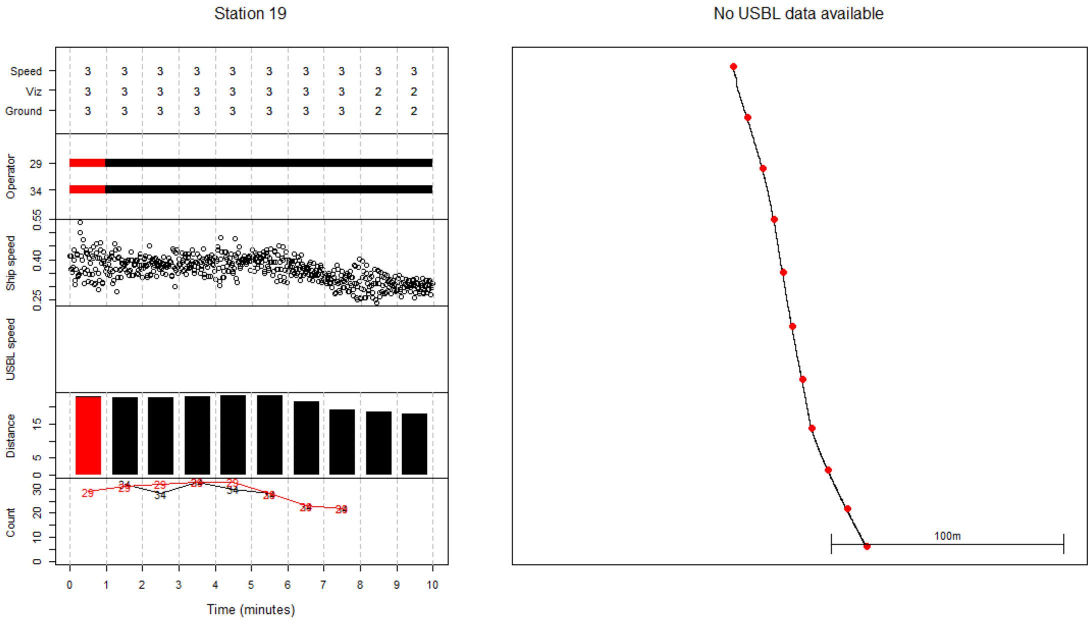


Figure 2: FU15 western Irish Sea grounds: R - tool quality control plot for station 19 of the 2018 survey.

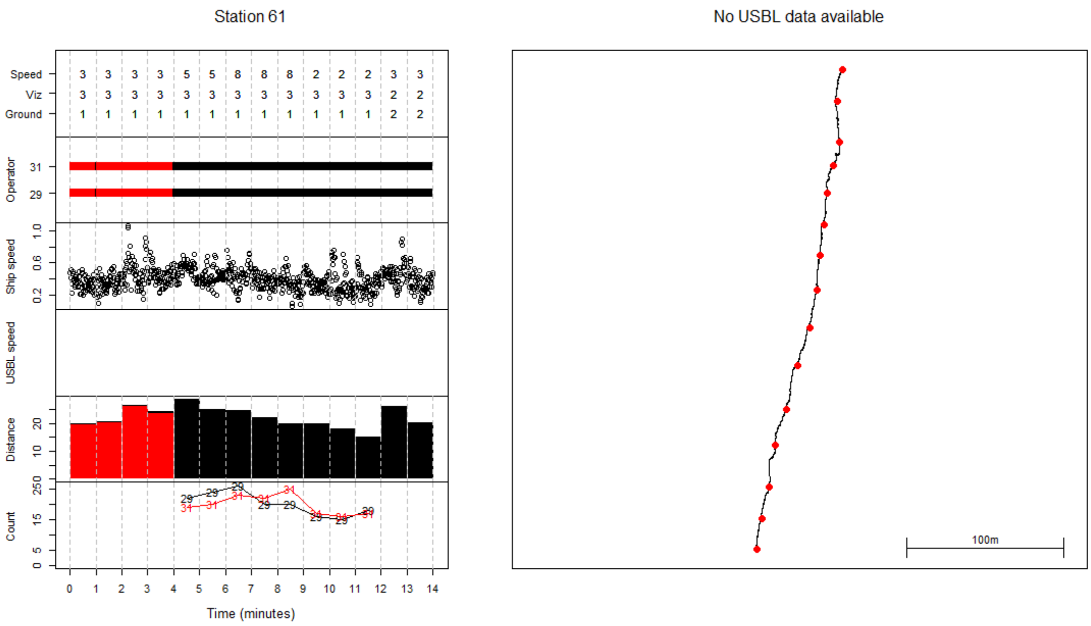


Figure 3: FU15 western Irish Sea grounds: R - tool quality control plot for station 61 of the 2018 survey.

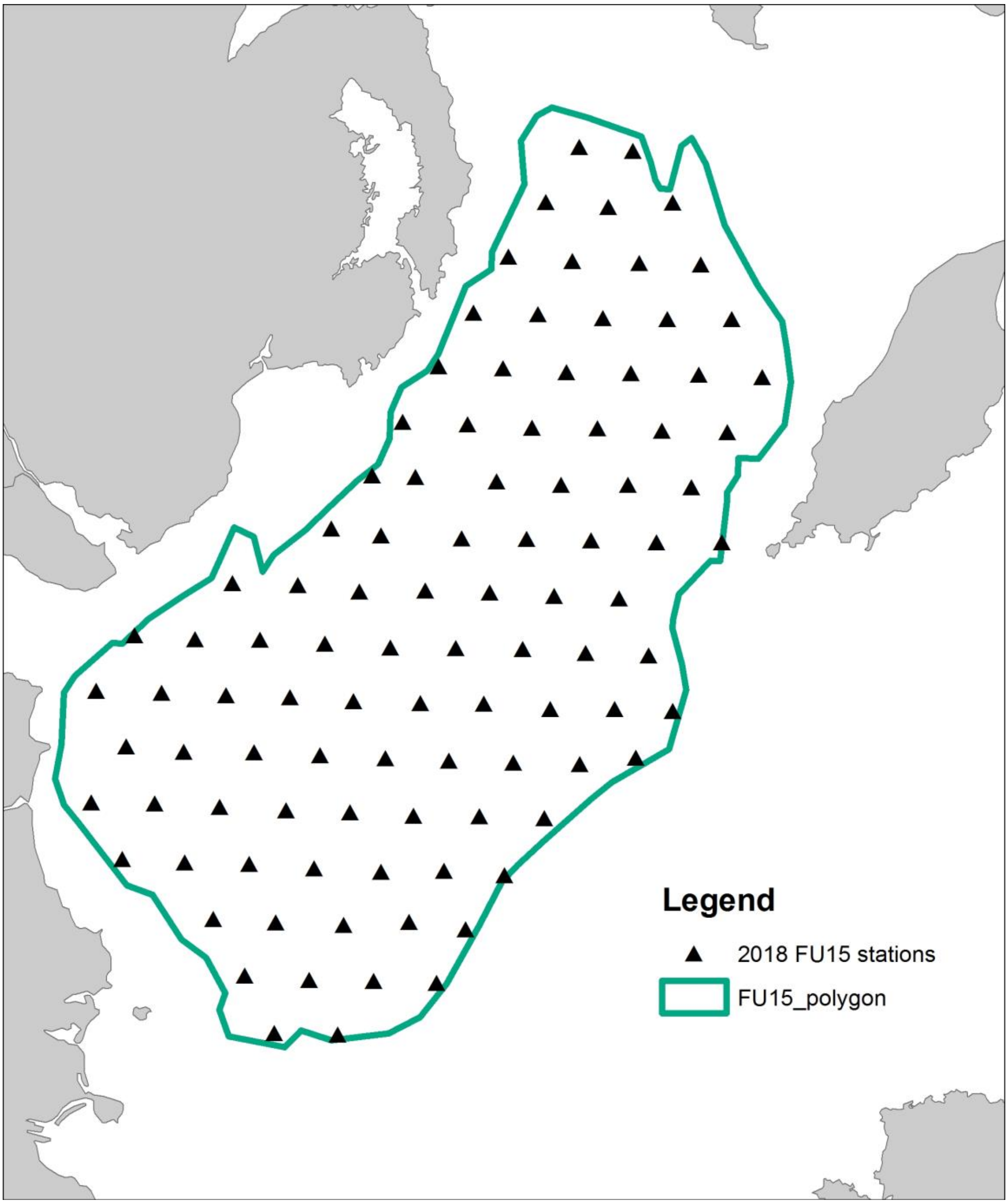


Figure 4: FU15 western Irish Sea grounds: Stations completed on the 2018 UWTV Survey.

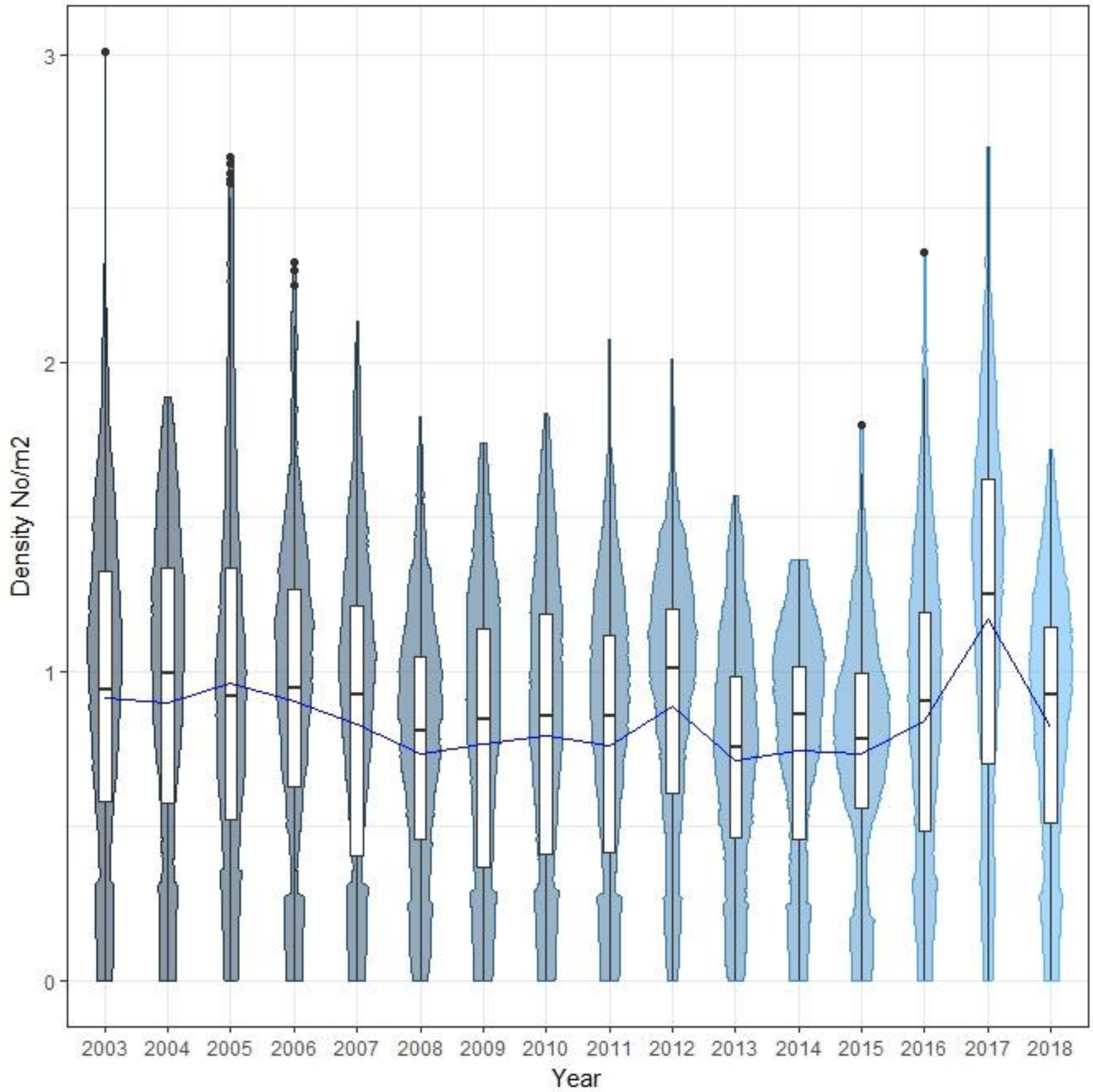


Figure 5: FU15 western Irish Sea grounds: Violin plot of burrow density distributions by year from 2003-2018.

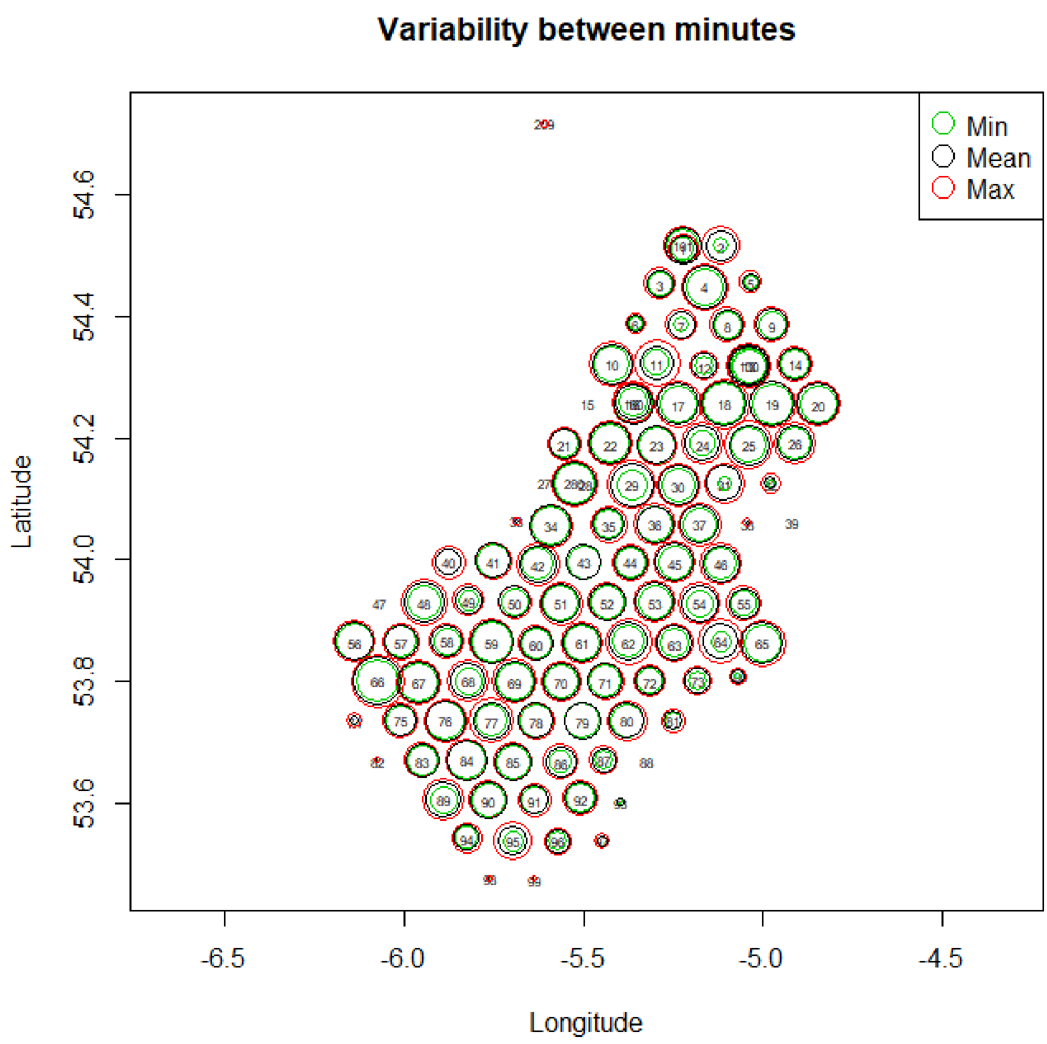


Figure 6: FU15 western Irish Sea grounds: Plot of the variability in density between minutes for each station in 2018.

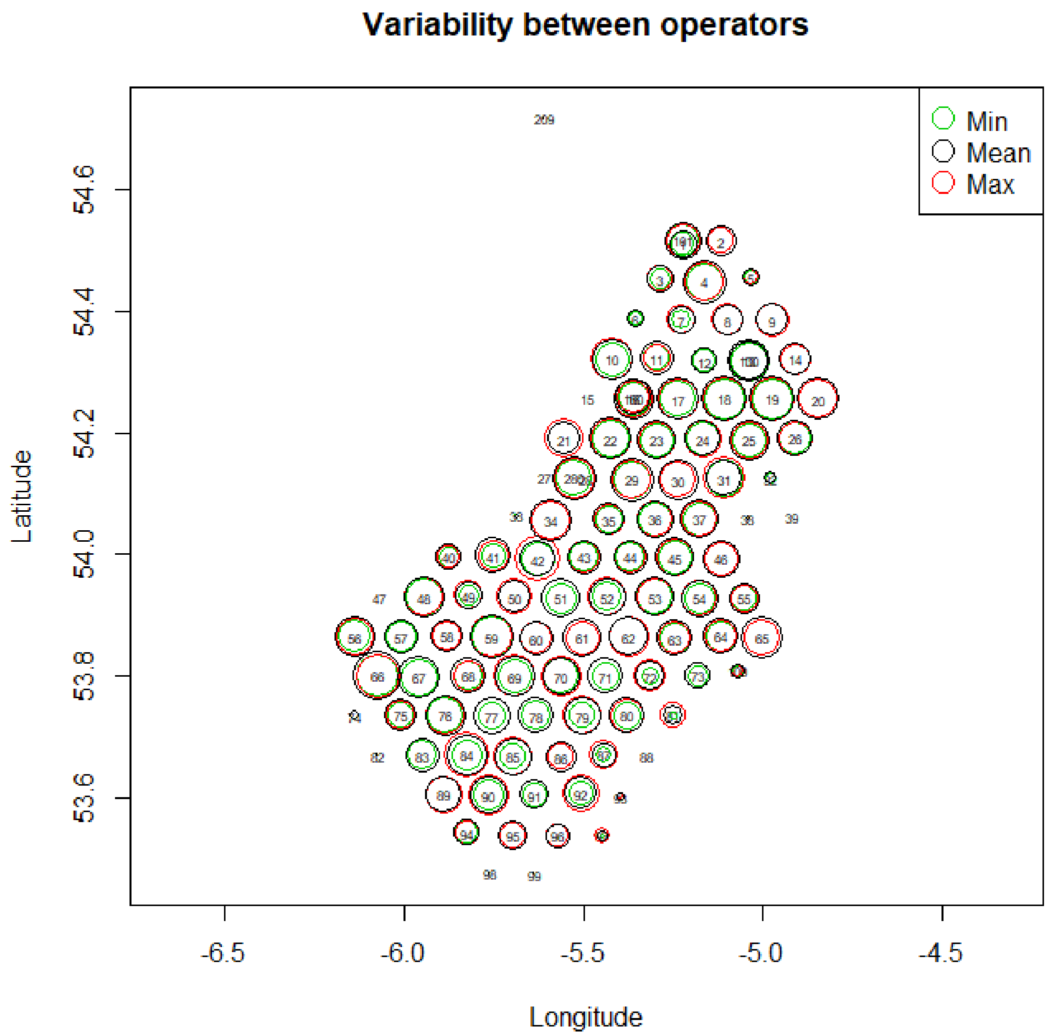
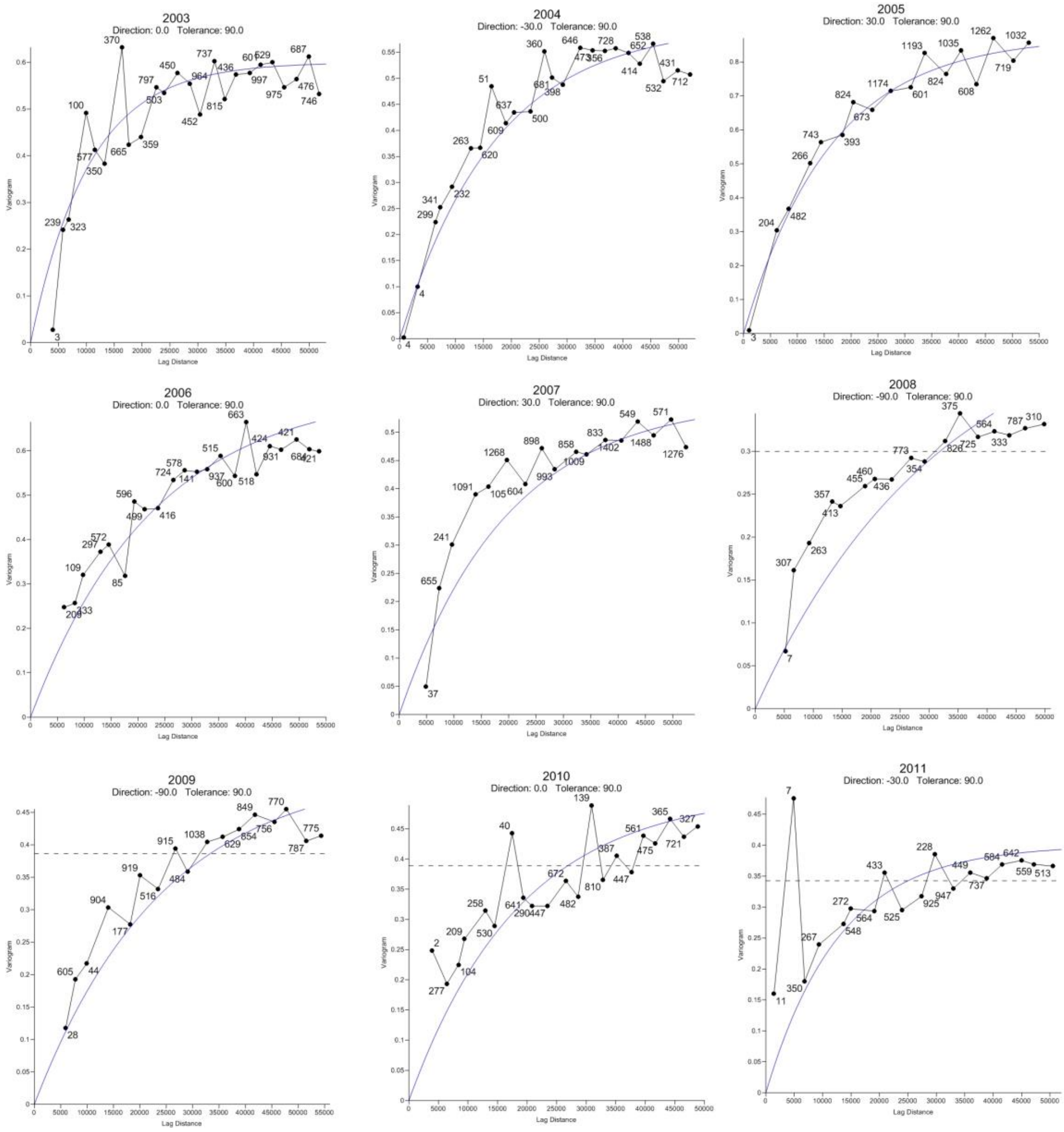


Figure 7: FU15 western Irish Sea grounds: Plot of the variability in density between operators (counters) for each station in 2018.


2003
Direction: 0.0 Tolerance: 90.0
2004
Direction: -30.0 Tolerance: 90.0
2005
Direction: 30.0 Tolerance: 90.0
2006
Direction: 0.0 Tolerance: 90.0
2007
Direction: 30.0 Tolerance: 90.0
2008
Direction: -90.0 Tolerance: 90.0
2009
Direction: -90.0 Tolerance: 90.0
2010
Direction: 0.0 Tolerance: 90.0
2011
Direction: -30.0 Tolerance: 90.0
Variogram
Lag Distance

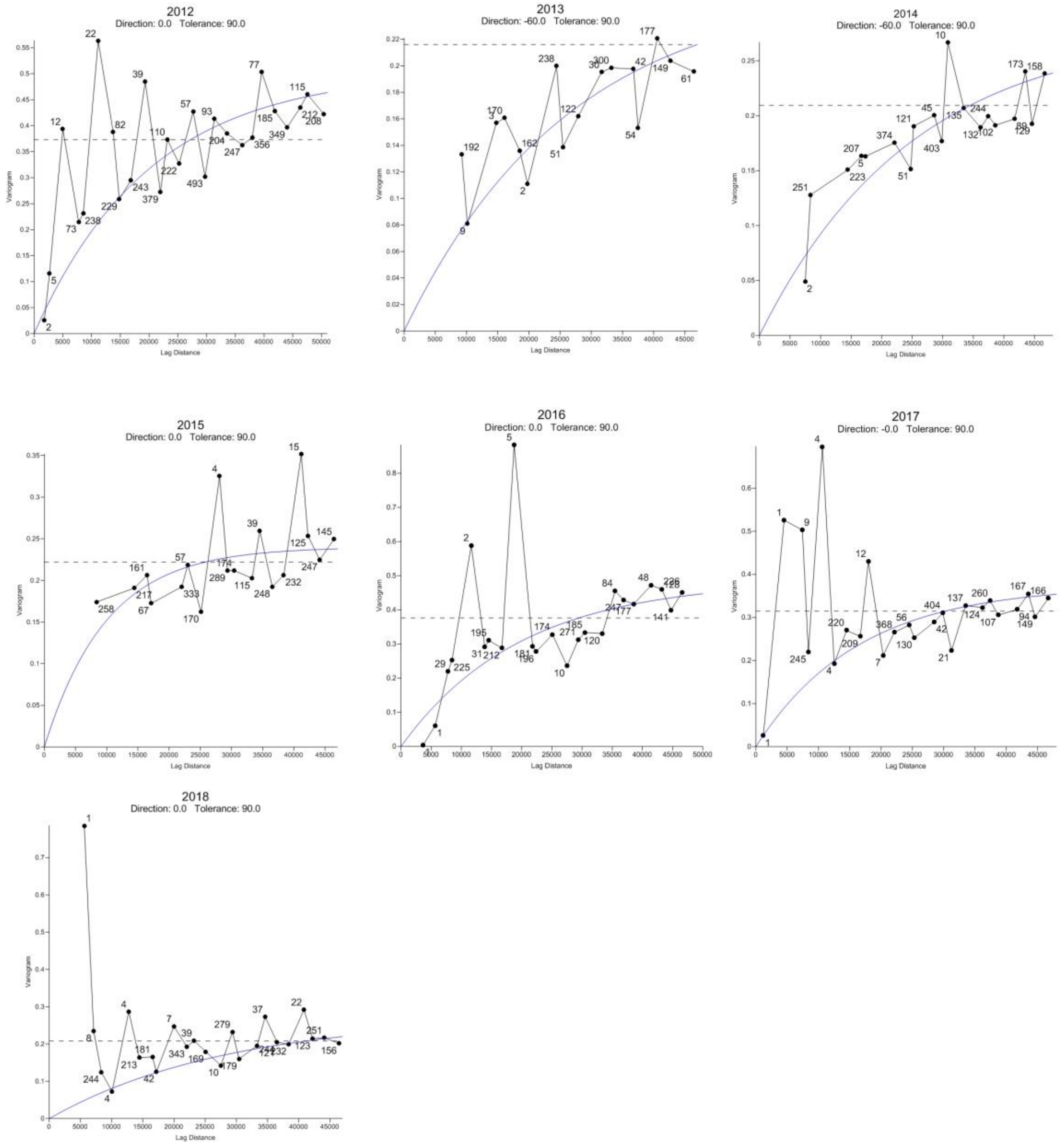


Figure 8: FU15 western Irish Sea grounds: Omnidirectional mean variograms by year from 2003-2018.

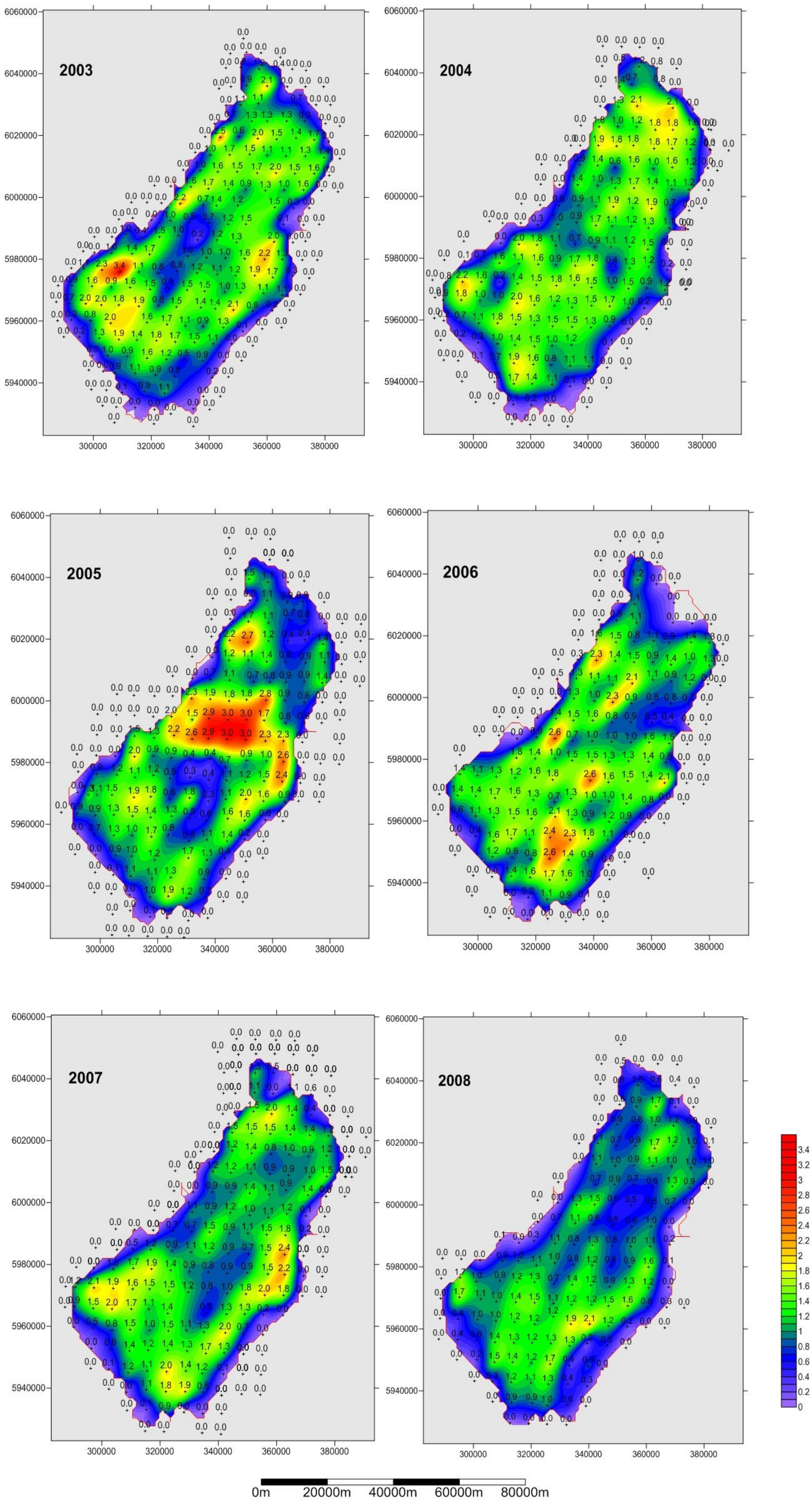


Figure 9: FU15 western Irish Sea grounds: Contour plots of the krigged density estimates by year from 2003 -2008.

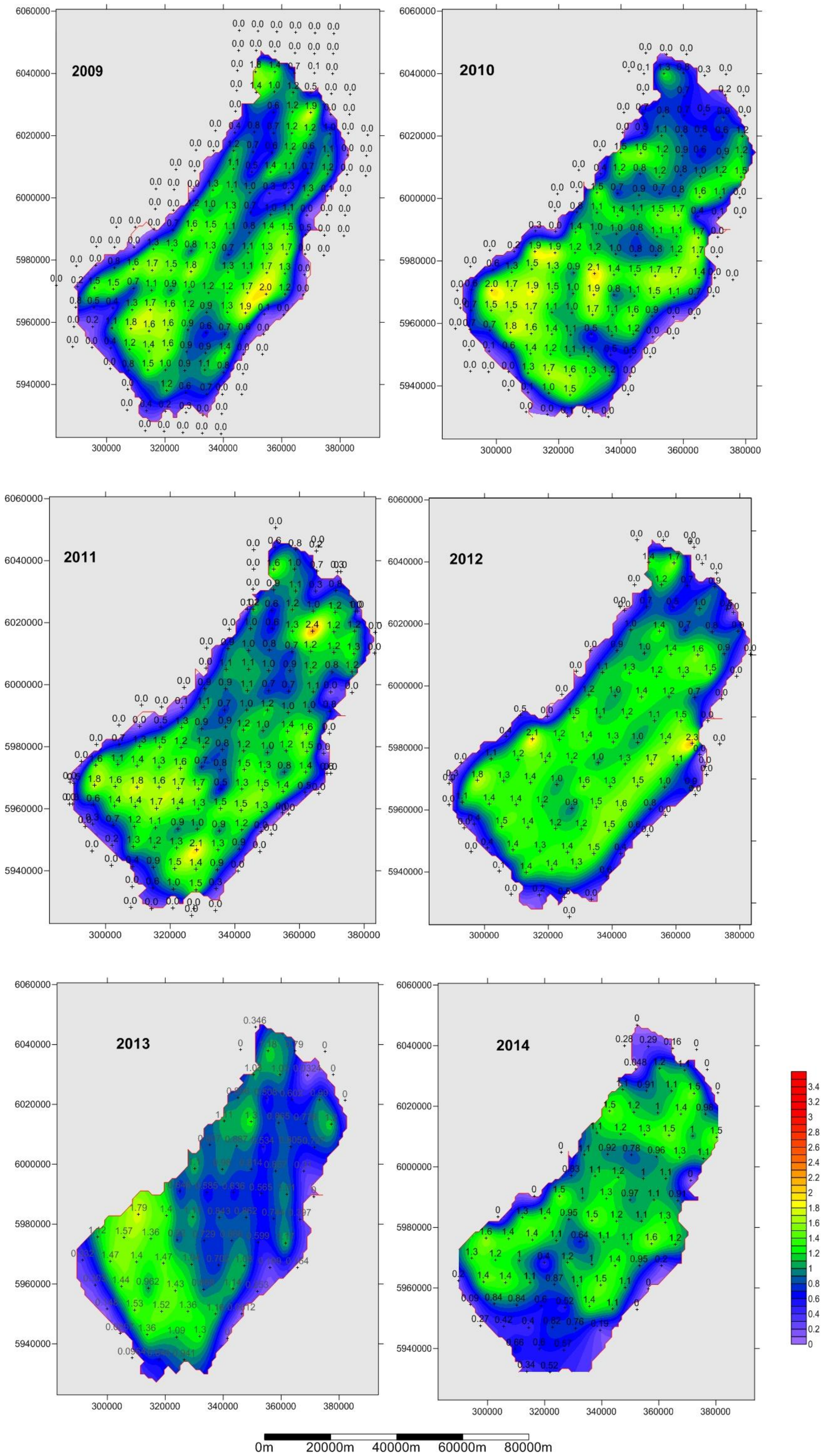


Figure 10: FU15 western Irish Sea grounds: Contour plots of the krigged density estimates by year from 2009 -2014.

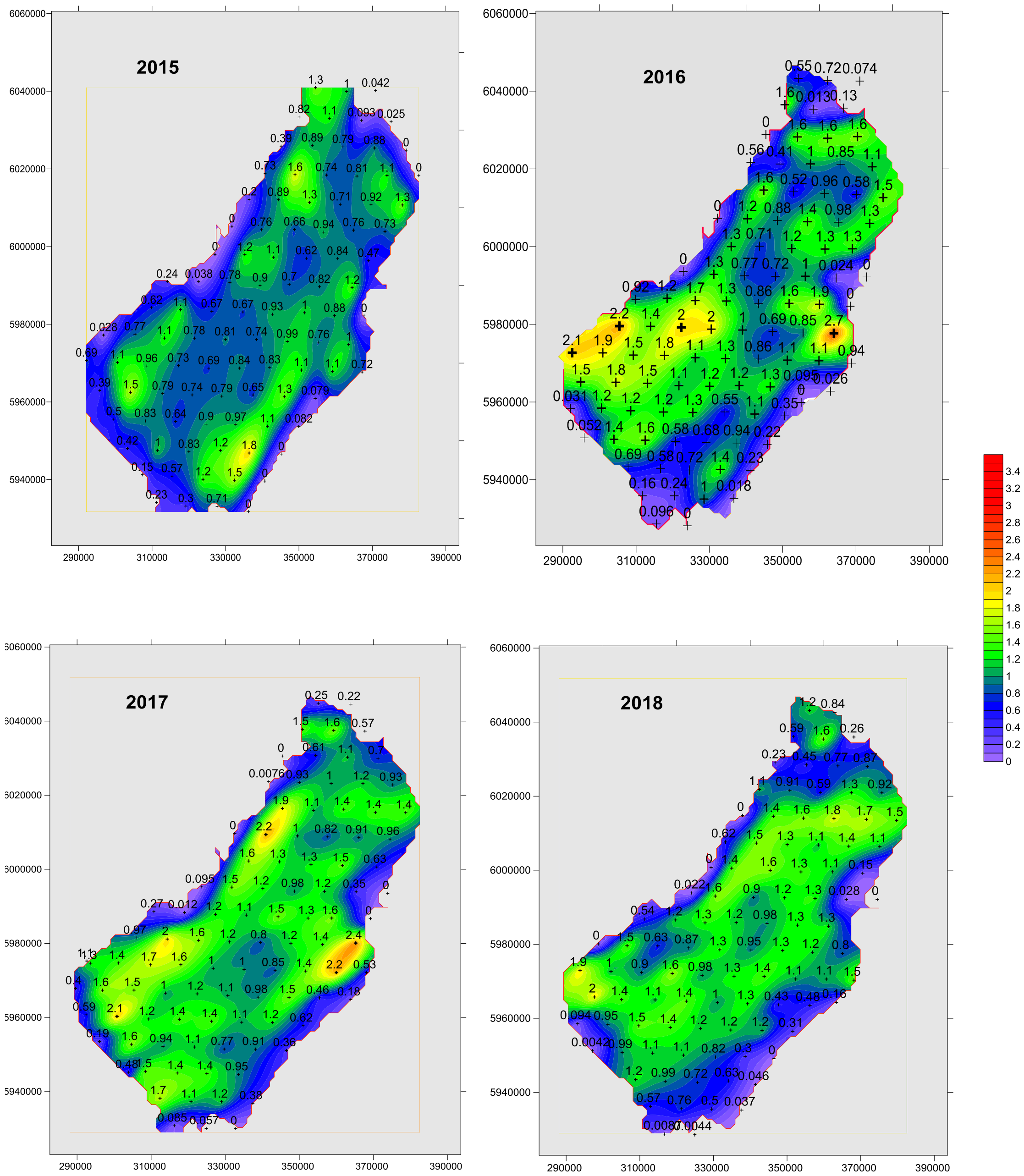


Figure 11: FU15 western Irish Sea grounds: Contour plots of the krigged density estimates by year from 2015 -2018.

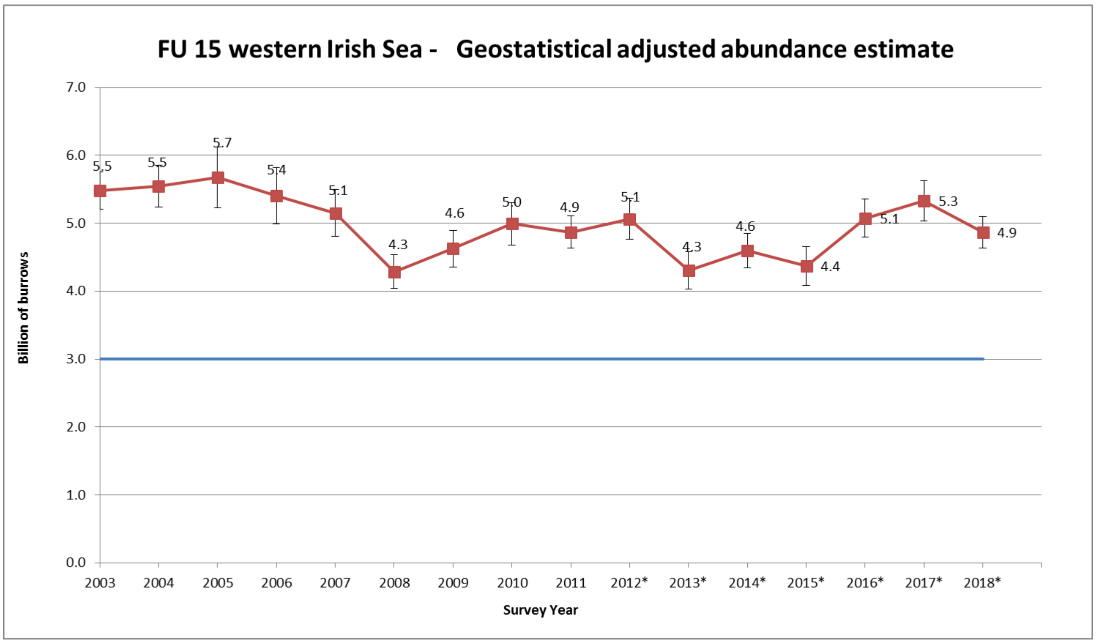


Figure 12: FU15 western Irish Sea grounds: Time series of geo-statistical adjusted abundance estimates (in billions of burrows) from 2003 -2018. Error bars correspond to the 95% confidence intervals calculated in EVA. Blue horizontal line is $B_{trigger}$ of 3.0 billion burrows.

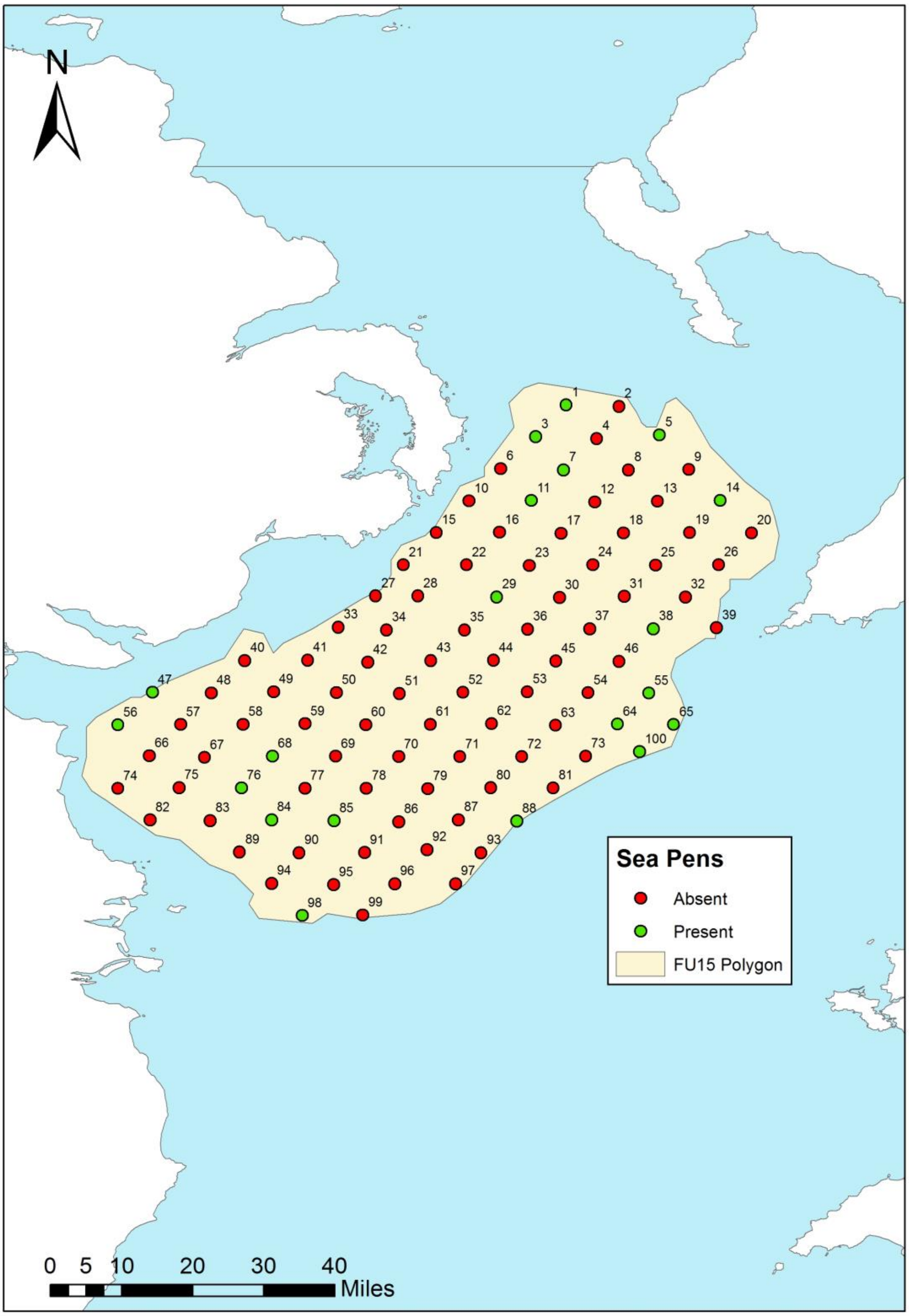


Figure 13: FU15 western Irish Sea grounds: Stations where *Virgularia mirabilis* was identified during 2018.

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: Cumulative bias factors for each *Nephrops* stock surveyed by UWTV method.

	Edge effect	Burrow detection	Burrow identification	Burrow occupancy	FU	*Cumulative Bias*
3&4 Skagerrak and Kattegat (IIIa)	1.3	0.75	1.05	1	FU3	1.1
6:Farn Deeps	1.3	0.85	1.05	1	FU6	1.2
7:Fladen	1.45	0.9	1	1	FU7	1.35
8:Firth of Forth	1.23	0.9	1.05	1	FU8	1.18
9:Moray Firth	1.31	0.9	1	1	FU9	1.21
10: Noup	1.31	0.9	1	1	FU10	1.21
11:North Minch	1.38	0.85	1.1	1	FU11	1.33
12:South Minch	1.37	0.85	1.1	1	FU12	1.32
13:Clyde	1.19	0.75	1.25	1	FU13	1.19
14: Irish Sea East	1.3	0.85	1.05	1	FU14	1.2
15:Irish Sea West	1.24	0.75	1.15	1	FU15	1.14
16: Porcupine	1.26	0.95	1.05	1	FU16	1.26
17:Aran	1.35	0.9	1.05	1	FU17	1.3
19:South Coast	1.25	0.9	1.15	1	FU19	1.3
20&21 Labadie	1.25	0.9	1.15	1	FU20	1.3
22:Smalls	1.35	0.9	1.05	1	FU22	1.3
34: Devil's Hole	1.3	0.85	1.05	1	FU34	1.2

Table 3: FU15 western Irish Sea grounds: Overview of geo-statistical results from 2003-2018.

FU 15	Year	Number of stations	Mean Density adjusted (burrows./m²)	Domain Area (km²)	Geo-statistical abundance estimate adjusted (billion burrows)	R-GeoStats Estimate	CV on Burrow estimate
Western Irish Sea	2003	160	0.99	5295	5.5	5.8	3%
	2004	147	1.00	5310	5.5	5.8	3%
	2005	141	1.02	5281	5.7	6.1	4%
	2006	138	0.97	5194	5.4	5.9	4%
	2007	148	0.93	5285	5.1	5.4	3%
	2008	141	0.77	5287	4.3	4.5	3%
	2009	142	0.83	5267	4.6	4.9	3%
	2010	149	0.90	5307	5.0	5.1	3%
	2011	156	0.88	5289	4.9	5.2	2%
	*2012	99	0.91	5291	5.1	5.5	3%
	*2013	80	0.78	5278	4.3	4.5	3%
	*2014	99	0.83	5272	4.6	4.6	3%
	*2015	100	0.79	5279	4.4	4.4	3%
	*2016	100	0.84	5260	5.1	5.2	3%
	*2017	101	0.90	5304	5.3	5.4	3%
	*2018	100	0.85	5791	4.9	4.9	3%

*reduced isometric grid

Table 4: FU15 western Irish Sea grounds: Short-term forecast management option table giving catch options for 2018 using the 2017 UWTV survey estimate.

Basis	Total catches*	Landings	Dead discards**	Surviving discards**	Harvest rate
	L+DD+SD	L	DD	SD	for L+DD
F_{MSY}	11,107	8,959	1,933	0,215	18.2
F_{2017}	6,469	5,218	1,126	0,125	10.6
F_{MSY} lower	7,568	6,104	1,317	0,146	12.4
F_{MSY} upper precautionary	11,107	8,959	1,933	0,215	18.2

Weights in tonnes.
* Total catches are the landings plus dead and surviving discards.
** Total discard rate is assumed to be 29.3% of the catches (in number); discard survival is assumed to be 10%.