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Report of the UWTV Survey on the Aran, Galway Bay and Slyne Head Nephrops Grounds 2006

by

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Abstract

The *Nephrops* fishery ‘at the back of the Aran Islands’ is the mainstay of the Ros a Mhíl fleet and sustaining this valuable fishery would be at the heart of any management plan for fisheries in the area. In 2006 the fifth in a series of annual UWTV survey was complete and the results of that survey together with a synthesis and analysis of the results. The survey is multi-disciplinary in nature collecting data on burrow abundances from UWTV, *Nephrops* biological data from beam trawls, oceanographic data form CTD, sediment data, multi-beam and other habitat data. A geostatistical analysis indicates that burrow densities and abundances have fluctuated considerably in space and time. Highest densities occurred in 2004 with the lowest densities in the 2006 survey. There may be a negative relationship between abundance an landings in the autumn and a positive relationship between observed densities and landings the following spring.
1 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 Irish *Nephrops* fishery is extremely valuable with landings in recent years worth around €30 m at first sale supporting an important indigenous processing industry. The *Nephrops* fishery ‘at the back of the Aran Islands’ can be considered the mainstay of the Ros a Mhíl fleet. 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 to enable sustainable management of the resources are urgently required.

This is the fifth in a time series of UWTV surveys on the ‘Aran grounds’. The 2006 survey was multi-disciplinary in nature; the specific objectives are listed below:

1. To complete the UWTV stations on a randomised fixed survey grid with 2.25Nmil spacing for the Aran (~70 stations), Slyne (3 stations) and Galway Bay (3 stations) *Nephrops* grounds.

2. To obtain 2005 estimates of distribution and abundance of prawns on the Aran, Slyne and Galway Bay grounds using underwater television. These will be compared with those collected previously to help determine the current status of these stocks.

3. To make use of the UWTV survey to estimate the densities of other shellfish and benthic organisms and to record evidence of trawl activity.

4. To acquire multibeam and backscatter information to define the sedimentary transition zones as well as to identify different types of benthic habitats.

5. To collect sediment samples to ground truth the multibeam data.

6. To complete a CTD section from 9°30W to 11°00W at 6km intervals on the 53°00N.

7. To examine the utility of the beam trawl for sampling *Nephrops*.

8. To develop and test a database to streamline data collection for this survey method.

9. To further test the utility of the GAPS – USBL system and STARFIX for acquisition of station by station navigational data.

This report details the data collected and results obtained during the survey.
2 Materials and Methods

2.1 Scientific Personnel

<table>
<thead>
<tr>
<th>Name</th>
<th>Service area</th>
<th>Role</th>
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<tbody>
<tr>
<td>Colm Lordan</td>
<td>MI-FSS</td>
<td>Scientist in Charge</td>
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<td>Fabio Sacchetti</td>
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<td>Deirdre O’Driscoll</td>
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<tr>
<td>Chris Allsop</td>
<td>MI-SPDS</td>
<td>Database developer</td>
</tr>
<tr>
<td>Fergal Dywer</td>
<td>MTDS</td>
<td>Electronics Technician</td>
</tr>
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</table>

Keiran Lyons and Glen Nolan MI-OSS carried out the analysis of CTD data collected during the survey.

2.2 Survey Plan

2.2.1 UWTV survey operations

Stations in Galway Bay and Slyne Head were either randomly picked or selected based on previously completed tows. On the Aran Grounds, which is the main survey area, a regularly spaced grid with stations at ~2.25 mile intervals (Figure 1). The regularly spaced grid with randomised start position provides the best statistical compromise between a totally randomised design and a fixed grid and subsequent geostatistical analysis of the results. Using a fixed grid means that full spatial coverage of the grounds is required to achieve a meaningful full biomass estimate.

At each station the UWTV sledge was deployed and once stable on the seabed a 10 minute tow as recorded on DVD. Vessel, calculated layback of the sledge and where possible the USBL position (position of sledge) and depth was logged for the duration of the tow.

2.2.2 Advanced mapping operations

The plan was to continuously acquire data using the multibeam and sub-bottom profiler while seaming from station on the UWTV station grid. These data would then be processed aboard to try and identify changes in benthic habitat or features on the seabed. Details of the systems and operational data collected are given in Table 1.

2.2.3 Oceanographic operations

Hydrographic stations were carried out during the survey at predetermined locations of section from 9°30W to 11°00W at 6km intervals on the 53°00N. Data on temperature, depth and salinity were collected using a Seabird 911 rosette sampler from 1m subsurface to 5m above the seabed. Post-processing of hydrographic data was carried out using SBE Data Processing and Ocean Data View ©.

2.2.4 Fishing operations

The Celtic Voyager 4 meter beam trawl was used during the survey for fishing operations. The objective was to examine the utility of this trawl in obtaining a sample (~200 individuals/haul) of the Nephrops population on the Aran grounds. The plan was to fish
for around 30 minutes during periods of peak *Nephrops* emergence as determined by the UWTV footage.

### 2.3 Equipment and system details and specifications

#### 2.3.1 UWTV Equipment

The equipment used during the UWTV survey is provided below:

- **UWTV Sledge (MTDS spec)**
  - 1 0E14-366 Underwater Video Camera (Angle XX, 12mm from sleeve, with a bottom of the screen measurement of 96/72cm in air/water)
  - 4 Miniature Underwater Lamps (2 used for duration of survey)
- **2 OE1232 Control Units**
- **1 300 Meter NC 13 Cable**
- **1 10m NC13 test lead**
- **2 Black box Converter Units (set-up for each camera)**
- **2 Sony DVD Recorders**
- **2 Sony DVD Players**
- **1 Sony Triniton monitor**
- **1 Sony Triniton Portable TV**

The back up equipment brought on the survey but not used is listed below:

- **1 OE14-108 Underwater Digital Stills Camera**
- **1 OE11-142 Underwater Flashgun**
- **1 220 Meter NC 13 Cable**
- **2 Spare bulbs for Miniature Underwater Lamp**

#### 2.3.2 Navigational Positioning

The primary positioning for this survey employed the Fugro Starfix 3100LRS DGPS. The specified accuracy for Starfix VBS is 2.0m (horizontal) and 5.0m (vertical) at the 95% confidence level. Differential GPS corrections are delivered to the vessel by means of a SCF broadcast message, via the EA-SAT Spot satellite link. The Starfix 3100LRS based on the vessels GPS derived position automatically selects the Starfix reference stations, providing corrections for this survey. The multibeam transducer was set as the common reference point and the time synchronization was handled by the Starfix time module and time stamped by the Fugro Oistar serial bus. This Starfix time program makes the most reliable time source on the network available to all machines.

A number of sensors were interfaced to the Fugro Starfix systems, via the IOWIN program. IOWIN decodes RS-232 data and makes it available to all programs within the Starfix Suite by publishing the decoded data as specific messages on the Fugro Message Manager.

The following is a list of sensors providing inputs to the Starfix system:

- Starfix VBS Position (Primary Position Source)
- Seapath DGPS NMEA Position (Secondary Position Source)
- Seapath Pitch / Roll / Heave and Heading (Primary Heading & P/R/H Source)
- Seapath GPS Position (Secondary Position Source)
- EM1002S – Centre beam (Nadir) depth
- EA400 – 33KHz and 210KHz channels.
- The water depth values have been logged in Fugro Starfix system and in Simrad datagram files.
- IXSEA USBL

In addition to decoding sensors for input, IOWIN can also output RS-232 data for external devices that may need fix or position information. In this case, outputs were sent to the CODA and video operation laptop. For video operations time and date, depth, cable out and three sets of navigational data; vessel position, FUGRO layback and USBL position, were logged for every two seconds.

The Starfix 3100LRS performance was generally good and reliable during the period of this leg and no problems were experienced with the satellite constellations.

Secondary positioning was by means of the Kongsberg Simrad Seapath 200 system, with position output to the EM1002S transceiver. The Seapath 200 provides a real-time heading, attitude, position and velocity solution by integrating the best signal characteristics of two technologies: Inertial Measurement Units (IMU’s) and the Global Positioning System (GPS). The system utilises a MRU 5 inertial sensor and two GPS carrier phase receivers as raw data providers. The raw sensor data is integrated into a Kalman filter in the processing unit. The Kalman filter is a proven and effective filtering technique for the integration of various sensors in a real-time environment. The filtered output provides heading, attitude and position data as required to the following systems:

- EM1002S Multibeam echo sounder (MBES)
- EA400 Singlebeam echo sounder (SBES)
- Starfix Navigation Software
- CODA dual sensor seismic record/playback system
- Starfix_LOGGING

**Starfix Navigation Suite**

The Starfix navigation package version 7.1 was employed throughout operations. The software may be loaded onto any IBM-compatible Pentium PC and is fully survey comprehensive, capable of referencing all towed and offset sensors, and issuing the data recorders with a corrected ASCII string. Various additional ancillary data may also be recorded.

The SPOT performance was generally good and reliable during the period of this survey and no problems were experienced with the satellite constellations.

Differential GPS corrections are delivered to the vessel user by means of a SCF broadcast message via the EA-SAT Spot satellite link, all available reference stations were used during the survey.

**2.3.3 EM1002S Multibeam echo sounder (MBES)**

The principal system employed for the recording of bathymetric data throughout the survey was the Kongsberg Simrad EM1002S multibeam echo sounder. The transducer is hull mounted on the vessel and operates at a frequency of 95kHz to 93kHz. Vessel heading and attitude corrections are input to the EM1002S via the Seapath 200; correcting bathymetric data in real time. Throughout operations, the system was set to a port/starboard operating angular coverage of 62°.

**Quality Control**
Even if the acquisition of multibeam data was not the main task of this survey, bathymetric data quality were monitored online and corrective actions were taken when possible in the case of data quality deterioration i.e. SVP’s were taken as necessary. From Line 0040 to line 0049 the data quality was not excellent due to some problem with heave and roll correction from Seapath. The problem was addressed and solved. Deformation of the swath was regularly observed during both surveys in 2005 and 2006. 

The surveyed Nephrops ground is generally very soft and this caused some problems in terms on pulse penetration and beam forming. Backscatter data acquired are of good quality.

**Sound Velocity Profiles**

Regular SVP profiles were taken throughout the survey in order to maintain acceptable bathymetric data quality. A SVP sensor instrument was employed. This has a direct velocity reading sensor and a temperature sensor, and is deployed from the stationary vessel from an oceanographic winch.

A total of 4 successful profiles were taken, during data acquisition. In general, the data quality achieved was quite good.

An AML Smart Sensor is also hull mounted at the forward end of the drop keel and provided a velocity input directly to the EM 1002 at the level of the transducer. This instrument has a direct velocity reading sensor and a temperature.

Even with all this corrections, a refraction on multibeam data was observed for most of the survey. This was probably caused by the presence of a strong termocline.

**2.3.4 Bathymetry EA400 SBES**

The Simrad EA400 single beam system is a single or multi frequency hydrographic echo sounder. The system installed on the R.V. *Celtic Voyager* has two transducers operating at 38kHz and 200kHz, respectively.

The system has three main components, which consist of the transducers, a general purpose transceiver and a PC based display interface running on Microsoft Windows®. Most of the echo sounder functions are implemented in the software. The bottom detection algorithm is implemented solely in the software with a separate computation for each frequency channel.

Interfaces are provided for the depth telegram output as well as navigation data, temperature sensor and heave sensor inputs. The system installed takes the navigation and heave data from the Seapath 200 and velocity profiles direct from any SVP instrument. The EA400 is interfaced to the Fugro Starfix navigation system; all three channels are logged in the FBF file and P294 file.

**2.3.5 IXSEA GAPS USBL system**

An IXSEA GAPS (Global Acoustic Positioning System) was employed throughout the survey to track, in real-time, the video sledge. The system consists of an array of four acoustic receivers mounted in the head unit. An INS (Inertial Navigation System) with external GPS is used to accurately position the acoustic array to enable tracking of up to four USBL transceivers. During this survey a single transceiver was mounted on the camera sledge.
As the head unit continually calculates the position of the acoustic array no calibration
is required to operate the unit.

The software setting adopted during the survey are given in below in Table 2. Interro-
gation of the beacon was set at 3.0s and a frequency of 1.95kHz to enable optimum
battery life and minimum disruption from the other surveying equipment that were in
use. Approximately every 6 hours the unit had to be recovered to replace the batteries
before operations continued.

2.3.6 Sub-Bottom Profiler
Shallow geological profiles were acquired employing the hull-mounted SES Probe
5000 sub bottom profiler transceiver. The 4-massa hull mounted transducer array was
triggered by a CODA DA200 topside system. Both raw navigation string and heave
compensation strings are fed into the Coda DA200 system.

The returned data were image enhanced by applying a user-selectable TVG. Variable
time delays were applied to remove the water column. Digital data were recorded in
CODA format. These data will be post-processed by the Marine Institute Advanced
Mapping Services team at a later date.

2.3.7 Beam Trawl operations
The beam trawl used had a 4m beam, chain foot rope, 80 mm standard diamond mesh
netting in the top-sheet and belly and a 20mm cod-end line. A warp to depth ratio of
3:1 was used and towing speed was around 2.8 knots. Navigational data was logged
as for the UWTV stations from STARFIX. All the *Nephrops* catches were sexed,
weighted and measured using digital callipers and logged using the Marine Institute
NEMESYS software.

2.3.8 Grab sampling
A Duncan and Associates day-grab was used for sediment sampling. After a few
unsuccessful deployments in deeper water a light cable-tie was used to mitigate
against premature firing on deployment. A small sample of sediment was retained and
frozen for lazer-particle size analysis at each station. Positional data was logged for
each sample using STARFIX and in the survey multilog database.

2.4 Analysis methods

2.4.1 Analysis of UWTV Burrow and *Nephrops* Count Data
All recounts were conducted by two trained “burrow identifying” scientists independent
of each other on board the RV during the survey. During this review process the visi-
bility, ground type and speed of the sledge during one-minute intervals were subjec-
tively classified using the classification criteria in the text table below. In addition the
numbers of *Nephrops* burrows (multiple burrows in close proximity which appear to be
part of a sing complex are only counted once), *Nephrops* in and *Nephrops* out of bur-
rows counted by each scientist for each one-minute interval was recorded. Notes were
also made on the occurrence of trawl marks, fish species and other species during the
one-minute interval. Finally, if any there was any time during the one-minute where
counting was not possible this was also estimated so that the time window could be
removed from the distance over ground calculations.

The resultant recount data were screened for one minute intervals with an 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 assuming that the sledge was flat on the seabed (i.e. no sinking).

The various descriptive statistics of burrow density were calculated as follows:

**Equation 1:** Sample mean density in each stratum ignoring spatial structure.

\[
\bar{Z}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} z_{i,j}
\]

Where \(z_{i,j}\) is the mean of all readers in station ‘j’ within stratum ‘i’ and \(n_i\) is the total number of stations in the stratum.

**Equation 2:** Sample variance in each stratum

\[
s_i^2 = \frac{1}{n_i - 1} \sum_{j=1}^{n_i} \left( z_{i,j} - \bar{Z}_i \right)^2
\]

**Equation 3:** Sample Standard Deviation

\[
s_i = \sqrt{s_i^2}
\]

**Equation 4:** Sample standard error

\[
S.E. = \frac{s_i}{\sqrt{n_i}}
\]

**Equation 5:** Sample coefficient of variation or relative standard error

\[
CV_{sam} = \frac{S.E.}{\bar{Z}_i}
\]

**Equation 6:** The burrow abundance estimate raised to the domain area

\[
B_i = A_i \times \bar{Z}_i
\]

Where \(A_i\) is the stratum area.

**Equation 7:** Variance of the burrow abundance estimate in the stratum.

\[
Var[B_i] = \frac{A_i^2 \times s_i^2}{n_i}
\]

All the calculations above ignore the spatial co-variance or other spatial structuring and assume that the samples to be independent and identically distributed.

To account for the spatial co-variance and other spatial structuring a geo-statistical analysis of the mean and variance was also carried out using SURFER Version 8.02 for stations within the main fishing area the Aran Grounds for all years. The spatial structure of the density data was studied through variograms. Initial the mid-points of each UWTV transect were converted to an absolute measure in kilometres form a point roughly in the middle of the grounds, 53°00 N and 10°04.2 W. 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 between 1-1.4 and maximum lag distance of between 19-20 km. A model variogram $\gamma(h)$, was produced with a nugget component and an exponential component (Equation 8). 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 8: Exponential Variogram Model

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

Where C is the scale for the structural component of the variogram and h is the anistropically.

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.

2.4.2 Analysis of multibeam data

The multibeam data were processed in Caris in real time. Backscatter and bathymetry data are plotted for interpretation using ArcGIS. The bathymetry data were girded at 20m resolution using and plotted using SURFER Version 8.02 and kriging interpolation.

2.4.3 Particle Size Analysis of sediment data

The PSA of the sediment samples was carried out by the University of Plymouth using a Low Angle Lazer Light Scattering (LALLS) method using a Malvern Instrument. A large range of variables were estimated and several key variables were selected for further analysis. Mapping of the sediment distributions was carried out using Surfer Ver. 8.02. For mapping PSA results were combined with those previously obtained from the Aran Grounds only. The relationship between sediment variables and observed Nephrops density was explored using R 2.4.1.

3 Results

The positions of all sampling events is plotted in Figure 1. Excellent weather helped in the completion of all the survey objectives. In summary, 73 underwater television stations were completed, 73 grab samples were obtained, 17 CTD casts were made on section on 53°N from 11°W to 10°W (approximately 52nmil), 4 SVPs and 4 stations were fished with the beam trawl.
3.1 **Nephrops UWTV results**

All stations were counted by two burrow counters independently. Comparison of these counts at one minute intervals are show in Figure 2. These indicate that there is some inter counter variability particularly as the densities increased but in general the correlations are good but there were few outliers. There are some indications of bias between one re-counter but this was general relatively low. All these counts were accepted as of reasonable quality and were used in further analysis.

Two possible methods for estimating the density at each station were explored. The first involved getting the mean for the various counters for the all countable minutes at each station. This is the station mean that has been used in previous years. The second involved looking at the inter-minute variability by taking a mean of each minute by minute density estimate. The second approach takes into account variability in densities over smaller areas but also may include variability due to differences between counters and variability due to accuracy of the area estimates each minute. The results for the second method are shown in Figure 3. These indicate a certain amount of variability at the minute by minute level but for most station it is not too significant (The geometric mean CV for all stations is in the order of 8%). Furthermore the minute by minute corresponds extremely well with the mean for the whole station (Figure 4).

A histogram of the observed burrow for 2006 and previous years on the Aran Grounds is presented in Figure 5. Summary parametric statistics for all years as calculated using equations 1-7 are presented in Table 3.1. The results indicate a significant decline in one year (~40%) in both mean density and total burrow abundance for 2006 to the lowest observed in the series only.

The geostatistical structural analysis is shown in the form of variograms in Figure 6. There are a few outliers apparent but they appear have little leverage on the variogram models observed. With the exception of 2006 a nugget is apparent in most years. 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. A comparison of the observer and expected density estimates for each year is given in Figure 7.

The blanked krigged contour plot and posted point density data are shown in Figure 8. The krigged contours correspond very well to the observed data. The results indicate the densities increased from 2002-2004 when very high densities were apparent throughout the ground. Densities subsequently decreased to the lowest levels observed in 2006. 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. The 2002 survey was based on a random design but geographically stratified to achieve reasonable coverage. In 2003 the survey was cut short due to technical problems and the eastern part of the ground was not covered. In 2004 the survey in June was again cut short due to extremely poor weather conditions but about a month later in late July additional stations were completed to achieve better coverage of the grid.

The summary statistics from this geostatistical analysis are given in Table 4. The mean densities and overall abundance estimate is extremely similar for most years (there is some difference in 2003 the year with poor sampling coverage). The geostatistical analysis provides a slightly lower variance estimate compared with the empirical approach. The geostatistical coefficient of variation estimate ranges between 25-46%.
3.2 Multibeam
Multibeam and Single beam data were acquired throughout the survey. In total 38 lines were recorded and processed. The preliminary interpretation of the backscatter imagery showed that the Nephrops ground was very homogeneous with little variation of sedimentary type. Some outcrops are visible near the border of Nephrops ground.

The multibeam was also used to create a detailed bathymetric map of the grounds. A summary plot is shown in Figure 9. The grounds range from around 80m along the eastern flank to over 110m at their deepest. There is a gradual deepening from east to west, with a steeper gradient in the north. There are a few shallower features are also apparent along the north-western flank and protruding ridge in the south-eastern corner.

3.3 Sediment sampling
The 2006 sediment data were combined with those in previous years to produce the most comprehensive sediment maps to date of the ground. The ground is mainly composed of poorly sorted mud with grain sizes of between 4-5 phi. Towards the northern boundary some coarsening of the sediment is apparent.

The relationships between the various sediment variables collected and the observed burrow densities is explored in Figure 11. There are various complex non-linear relationships apparent. Density is strongly correlated with the mud and silt variables and conversely negatively correlated with sand. Burrow density is positively correlated with modal and mean size. The relationship is complex with almost no burrows at mean sizes < 4 phi. Burrow density is close to zero at mud fractions <40% before increasingly rapidly up to around 60%. At higher percentages of mud the density is fairly similar. Where the clay percentage increases above 6% the density estimate decrease rapidly. There is an apparently domed relationship between various sorting variables (sorting, skewness and kurtosis) and density suggesting some optimal for these in the mid range of the observations.

3.4 Oceanographic Conditions
The Aran Grounds is oceanographically characterised as an area of low energy and not much current activity. The temperature close to the sea bed is fairly homogeneous throughout the year compared with the surface. The results of the CTD section are presented in Figure 12. In June 2006 the bottom temperature was around 10°C and a shallow thermocline was apparent close to the surface with surface temperatures reaching 16°C. The salinity shows that water is slightly fresher than normal probably due to the very wet May. There is some weak evidence at around 10°15W of the bottom density current which sets up in this area from the salinity profiles. The transmissometer shows anomalous low near 10W. This is very interesting because the same thing was found on the 53N section done in May. The reasons for this are not yet known.

3.5 Beam Trawl Results
A summary of the results of fishing operations is given in Table 5 and Figure 13. In all just over 17Kg of Nephrops were caught in the four tows there were minor by-catches of other benthic species and a few fish which were not sampled quantitatively. Catch rates (<0.06 Nephrops/m2) were well below the observed burrow density estimates.
No significant differences were observed in the size distribution caught by station or sex. For females it was possible to fit a maturity ogive to the macroscopic maturity stages assigned. The $L_{50}$ estimate was around 20mm carapace length.

### 3.6 Other acoustic results

The Echoplus data were permanently acquired, and in general they showed a fair correspondence of classification in terms of hardness and roughness with the backscatter images interpreted on the fly. The results of the sub-bottom profiler are not yet fully interpreted.
4 Discussion and Conclusions

All survey objectives were successfully met thanks to the excellent weather throughout and no technical problems. The survey has developed into a multidisciplinary survey of the ecosystem on the Aran Grounds and adjacent areas. Over the last number of years, the data collection and analysis has developed considerably. This was the first survey where almost all navigational data for the sledge was based on USBL positioning system. Previously, vessel layback was the only source of sledge positioning. The resulting comparisons indicate that both vessel layback and distance over ground both correspond very closely to the USBL estimates although the positions were off set somewhat. We conclude that although the USBL estimates of distance over ground are optimal when these are not available then either layback or vessel distance over ground is adequate.

This survey has been developing consistently since 2002. The primary objective of the survey is to provide an abundance estimate for *Nephrops* on the Aran and adjacent grounds. The survey targets three geographically isolated *Nephrops* grounds (Galway Bay, Slyne Head, and the Aran Grounds) of which the Aran Grounds is by far the largest and most important in terms of the fishery. This is the fifth survey in the series and the results thus far indicate large inter-annual changes in both mean density, total abundance, and the spatial distribution of the highest densities observed.

The question arises are these large fluctuations in density real or some artefact of the survey design or some kind of year effect? Similar UWTV surveys have occurred in Scottish waters since the mid-1990s and these also indicate substantial dynamic changes in biomass over the time series to date (ICES, 2006a). For example, the dynamic range in Scottish stocks indicates the maximum abundance can be up to three times greater that minimum abundance in the same area and inter-annual fluctuations of the in the order of 50% can occur. However, if such large changes occur in abundance are these changes reflected in the fishery by variations in landings? To examine this, the relationship between burrow abundance and landings was examined (Figure 14). The fishery can be characterised by two main periods: the autumn fishery and the fishery the subsequent spring. Using annual data there wasn't a convincing relationship between the survey and the landings. However, examining the data on a finer time scale, the results suggest that there is a negative relationship between survey abundance in June and landings in the autumn and a positive relationship with the fishery the subsequent spring. The results here are based on few data points and the landings are based on logbook data which may not reflect true levels of catch since discards and misreporting have not been taken into account (ICES, 2006b).

This year for the first time a geostatistical analysis of the survey data was completed and the results compared favourably with the empirical estimates of mean and uncertainty. The results indicate that both methods yielded very similar estimates of burrow abundance and uncertainty. The main advantage of the geostatistical analysis is that the large changes in density at the boundary of the ground is considered in the calculation of the survey variance by forcing the model towards zero just past the perimeter of the ground. This is to a certain extent also done in the empirical approach by continuing to survey past the boundary of the grounds and including these data in the domain and analysis. Further work could be carried out to improve the geostatistical analysis.
and to look at including other factors such as depth, sediment, fishing effort etc. in the analysis.

Prior to 2002 there was no data on the sediments or habitat on the Aran Grounds. There is an increasing knowledge of the physical habitat thanks to these surveys. The results of the sediment analysis indicate that the observed burrow densities and sediment are linked to various sediment variables. Further work will be undertaken to model this relationship more fully. In addition work is currently underway to examine the multibeam data in relation to both the sediment and burrow densities. In addition the sun-bottom profiler should give some new insights into the sediment thickness throughout the ground. The data to date indicates that habitat throughout the ground is fairly homogeneous therefore future work could concentrate on mapping the boundaries of the ground more extensively.
Acknowledgements

The authors wish to extent their thanks to the master, Denis Rowan, and all crew of R.V. Celtic Voyager who’s continued hard work made this and previous surveys so successful. Special thanks to Fergal Dwyer who kept all the technology working despite several attempts to fail. Thanks to all in RVOPs and P&O Maritime for their help with logistical arrangements particularly Caitriona Nic Aonghusa, Barry Kavagnagh and Bill Dwyer. Thanks to Rob Bunn who helped with the mobilisation and testing of all UWTV equipment. Thanks to Hans Gerritsen, Sara Benetti and Xavier Harlay for their assistance with interpretation of the results. The PSA was carried out by Dr. Richard Hartley of the School of Geography University of Plymouth. Free R-software has been used for this work and the authors would like to thank the R development core team and all contributors to the R project (http://www.r-project.org).
References/Bibliography


Appendices

Appendix 1 Survey Narrative CV0510 Aran UWTV 2005

1 June 2006


2 June 2006

At Station 4 STARFIX programme crashed but was successfully retrieved and day Grab successful on fourth attempt in 98m of water. At Station 3, Grab successful on third attempt in 100m of water. Headed to station 7 as station 3 on the edge of the ground with zero counts and sand. At station 9 the grab was secured with a light cable tie before deployment which improved success rate. Station 14, grab successful on second attempt. Station 13, STARFIX crashed and was retrieved.

3 June 2006

Station 25, USBL didn’t work for this run so have layback position. Changed batteries and tested in dry lab worked fine. Also Fabio changed the beacon as signal was really weak during test-Fergal to test beacon. Before Station 36, light on right side the connection was loose- so cleaned and reconnected it before redploying also USBL batteries changed. SVP (Sound Velocity Profile) taken after station 36. At station 32 the light on right side tripped again on deployment on recovery the connector had been pulled loose. This was cleaned and then reconnected.

4 June 2006

The light worked normally at the next station. Station 48, camera seemed out of focus and lights very bright but continued with tow. Before deploying at station 49, GUI programme was reloaded to adjust focus but it wouldn’t initialise after 45 minutes-decided to go ahead with TV tow and test software on another machine between stations and still no success. 5 fishing boats in the area. Camera focus from Station 49 seemed fine no problems. Station 51, USBL pinger did not chirp when test and then switched on-so replaced bottle- worked for duration of tow. The batteries were change although they had only worked for 3 hrs and it started working again. Station 52 the, USBL pinger did not chirp when test and then switched on-so replaced bottle with the one taken off previously it worked for duration of tow. Station 53 the USBL pinger again didn’t work when tested so was taken off for the tow.

5 June 2006

Headed to station 72 after completing station 70 as fishing vessel towing near to the station. USBL not working station 72 and also high counts at this station-so extended the edge of survey plan eastward by 1 station 54, which on surveying was an edge. At station 78 the sledge was deployed but there were rocks on the seabed so it was hauled back immediately a short amount of footage was recorded. At station 77 the ground was still very hard so the vessel proceeded to station 76. Station 79, 80 and 81 was rocky ground mapping the southern edge of the grounds- recorded short footage
but no grab sample. Aran Grounds UWTV survey stations completed at 18:00 hours. Recomenced UWTV operations on Slyne Head at around 21:00, three stations completed successfully and proceeded to start of CTD line.

6 June 2006

Commenced CTD operations around 3:30. CTD operations completed at 13:40. Operations suspended until fishing after dark. Commenced fishing operations at 9pm. Beam Tow 1 and 2 were completed successfully.

7 June 2006

Tow 3 gear deployed at 3.11, 300 m wire out. Tow 4 gear deployed at 4.16 300m wire out. On station at 7.30 for station 103 in Galway Bay. Resumed UWTV operations at station 103 in Galway Bay. Finished UWTV operations at 10:00 and commenced demobilisation.

8 June 2006

Vessel was fully demobilised.
Table 1  R.V. Celtic Voyager operational payload systems and data sets collected on the Aran Nephrops UWTV survey 2006.

<table>
<thead>
<tr>
<th>System</th>
<th>Data Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fugro VBS Positioning &amp; Seapath 200</td>
<td>Permits GPS-framework positioning and injects time, date and position data to all peripherals and towed sensors.</td>
</tr>
<tr>
<td>Simrad EM1002S multibeam echo sounder</td>
<td>100% coverage giving bathymetry and backscatter images that are processed, via the CARIS software into paper and digital charts at various scales.</td>
</tr>
<tr>
<td>EA400 dual frequency single beam echo sounder</td>
<td>Depth data integrated with the swath data. Data retained for archiving and future research.</td>
</tr>
<tr>
<td>SBE Model 11 CTD AML sound velocity profiler</td>
<td>Velocity profiles for echo sounder calibration. Data retained in digital format for archiving and future research</td>
</tr>
<tr>
<td>Hull-mounted SES Probe 5000 sub bottom profiler transceiver triggered by a CODA DA200 topside system.</td>
<td>Coda format data</td>
</tr>
<tr>
<td>IXSEA GAPS USBL system</td>
<td>Ultra short baseline positioning system for towed bodies or ROV applications</td>
</tr>
</tbody>
</table>

Table 2  IXSEA GAPS USBL system supervision settings adopted during the 2006 Aran Nephrops UWTV survey.

<table>
<thead>
<tr>
<th>Supervision screen</th>
<th>Parameter</th>
<th>Setting adopted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic Array</td>
<td>Interrogation Frequency</td>
<td>19500 Hz</td>
</tr>
<tr>
<td></td>
<td>Environment</td>
<td>Normal</td>
</tr>
<tr>
<td>GPS</td>
<td>Baud Rate</td>
<td>9600 Bauds</td>
</tr>
<tr>
<td></td>
<td>Protocol</td>
<td>GPGGA</td>
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<tr>
<td></td>
<td>Parity</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Stop Bit</td>
<td>1.0</td>
</tr>
<tr>
<td>Output</td>
<td>Period</td>
<td>499ms</td>
</tr>
<tr>
<td></td>
<td>Baud Rate</td>
<td>19200 Bauds</td>
</tr>
<tr>
<td>Processor</td>
<td>Parity</td>
<td>Stop Bit</td>
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<tr>
<td>--------------------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>1.0</td>
</tr>
<tr>
<td>Position Cycle Recurrence</td>
<td>3s</td>
<td></td>
</tr>
<tr>
<td>Acoustic Recurrence</td>
<td>Internal Fixed</td>
<td>3s</td>
</tr>
<tr>
<td>Recurrence</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3  Summary parametric statistics for the Nephrops UWTV surveys of the Aran and adjacent grounds form 2002-2006.

<table>
<thead>
<tr>
<th>Ground</th>
<th>Year</th>
<th>Number of stations</th>
<th>Area Surveyed (M²)</th>
<th>Burrow count</th>
<th>Mean Density (No./M²)</th>
<th>Var</th>
<th>Standard Deviation</th>
<th>Standard Error</th>
<th>t-value</th>
<th>95% CI (Relative SE)</th>
<th>CViid (Relative SE)</th>
<th>Domain Area (km²)</th>
<th>Raised abundance estimate (million burrows)</th>
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</thead>
<tbody>
<tr>
<td>Aran Grounds</td>
<td>2002</td>
<td>49</td>
<td>9,450</td>
<td>7,599</td>
<td>0.81</td>
<td>0.19</td>
<td>0.43</td>
<td>0.06</td>
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<td>0.12</td>
<td>7.6%</td>
<td>978</td>
<td>794</td>
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<tr>
<td></td>
<td>2003</td>
<td>42</td>
<td>11,398</td>
<td>11,652</td>
<td>1.09</td>
<td>0.17</td>
<td>0.41</td>
<td>0.06</td>
<td>2.02</td>
<td>0.13</td>
<td>5.9%</td>
<td>978</td>
<td>1,062</td>
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<tr>
<td></td>
<td>2004</td>
<td>64</td>
<td>13,040</td>
<td>18,742</td>
<td>1.38</td>
<td>0.43</td>
<td>0.66</td>
<td>0.08</td>
<td>2.00</td>
<td>0.16</td>
<td>6.0%</td>
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<tr>
<td></td>
<td>2005</td>
<td>70</td>
<td>12,373</td>
<td>13,321</td>
<td>1.06</td>
<td>0.26</td>
<td>0.51</td>
<td>0.06</td>
<td>1.99</td>
<td>0.12</td>
<td>5.8%</td>
<td>978</td>
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<tr>
<td></td>
<td>2006</td>
<td>67</td>
<td>10,527</td>
<td>6,928</td>
<td>0.61</td>
<td>0.10</td>
<td>0.31</td>
<td>0.04</td>
<td>2.00</td>
<td>0.08</td>
<td>6.2%</td>
<td>978</td>
<td>600</td>
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<tr>
<td>Galway Bay</td>
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<td>7</td>
<td>1,299</td>
<td>2,017</td>
<td>1.58</td>
<td>0.14</td>
<td>0.37</td>
<td>0.14</td>
<td>2.45</td>
<td>0.34</td>
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<td>n/a</td>
<td>n/a</td>
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<tr>
<td></td>
<td>2003</td>
<td>3</td>
<td>591</td>
<td>941</td>
<td>1.60</td>
<td>0.09</td>
<td>0.29</td>
<td>0.17</td>
<td>4.30</td>
<td>0.73</td>
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<td>n/a</td>
<td>n/a</td>
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<tr>
<td></td>
<td>2004</td>
<td>9</td>
<td>2,312</td>
<td>1,625</td>
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<td>0.32</td>
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<td>n/a</td>
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<td>2005</td>
<td>4</td>
<td>661</td>
<td>1,107</td>
<td>1.67</td>
<td>0.04</td>
<td>0.20</td>
<td>0.10</td>
<td>3.18</td>
<td>0.32</td>
<td>6.0%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>3</td>
<td>522</td>
<td>522</td>
<td>1.01</td>
<td>0.06</td>
<td>0.25</td>
<td>0.15</td>
<td>4.30</td>
<td>0.63</td>
<td>14.5%</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>Slyne Grounds</td>
<td>2002</td>
<td>5</td>
<td>1,216</td>
<td>1,027</td>
<td>0.85</td>
<td>0.04</td>
<td>0.19</td>
<td>0.08</td>
<td>2.78</td>
<td>0.23</td>
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<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.00</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>3</td>
<td>827</td>
<td>531</td>
<td>0.68</td>
<td>0.07</td>
<td>0.27</td>
<td>0.15</td>
<td>4.30</td>
<td>0.66</td>
<td>22.7%</td>
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<td>n/a</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>3</td>
<td>531</td>
<td>294</td>
<td>0.55</td>
<td>0.00</td>
<td>0.05</td>
<td>0.03</td>
<td>4.30</td>
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<td>5.6%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>3</td>
<td>526</td>
<td>210</td>
<td>0.41</td>
<td>0.04</td>
<td>0.20</td>
<td>0.11</td>
<td>4.30</td>
<td>0.49</td>
<td>28.1%</td>
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</table>

Table 4  Summary geostatistics for the Nephrops UWTV surveys of the Aran Grounds form 2002-2006.

<table>
<thead>
<tr>
<th>Ground</th>
<th>Year</th>
<th>Number of stations</th>
<th>Number of boundary points</th>
<th>Mean Density (No./M²)</th>
<th>Var</th>
<th>Standard Deviation</th>
<th>CVgeo (Relative SE)</th>
<th>Domain Area (km²)</th>
<th>Raised abundance estimate (million burrows)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aran</td>
<td>2002</td>
<td>49</td>
<td>27</td>
<td>0.82</td>
<td>0.10</td>
<td>0.32</td>
<td>39%</td>
<td>892</td>
<td>753</td>
</tr>
<tr>
<td>Aran</td>
<td>2003</td>
<td>42</td>
<td>27</td>
<td>0.89</td>
<td>0.16</td>
<td>0.41</td>
<td>46%</td>
<td>894</td>
<td>817</td>
</tr>
<tr>
<td>Aran</td>
<td>2004</td>
<td>64</td>
<td>26</td>
<td>1.49</td>
<td>0.16</td>
<td>0.40</td>
<td>27%</td>
<td>889</td>
<td>1369</td>
</tr>
<tr>
<td>Aran</td>
<td>2005</td>
<td>70</td>
<td>28</td>
<td>1.14</td>
<td>0.08</td>
<td>0.28</td>
<td>25%</td>
<td>886</td>
<td>1,047</td>
</tr>
<tr>
<td>Aran</td>
<td>2006</td>
<td>67</td>
<td>26</td>
<td>0.69</td>
<td>0.05</td>
<td>0.23</td>
<td>33%</td>
<td>889</td>
<td>635</td>
</tr>
</tbody>
</table>
Table 5. The results of beam trawl catches on the Aran Grounds in June 2006.

<table>
<thead>
<tr>
<th>Beam Trawl</th>
<th>Start</th>
<th>End</th>
<th>Distance over ground (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Time</td>
<td>Longitude</td>
</tr>
<tr>
<td>Tow 1</td>
<td>06.01.80</td>
<td>20:00:50</td>
<td>52.87986</td>
</tr>
<tr>
<td>Tow 2</td>
<td>06.01.80</td>
<td>21:02:11</td>
<td>52.95423</td>
</tr>
<tr>
<td>Tow 3</td>
<td>07.01.80</td>
<td>02:15:00</td>
<td>53.02103</td>
</tr>
<tr>
<td>Tow 4</td>
<td>07.06.06</td>
<td>03:14:31</td>
<td>53.08309</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beam Trawl</th>
<th>Weight of Nephrops Caught (kg) in each tow</th>
<th>Beam Trawl</th>
<th>Weight of Nephrops Caught (kg) in each tow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Female Pale</td>
<td>Female Medium</td>
</tr>
<tr>
<td>Tow 1</td>
<td>3.598</td>
<td>0.02</td>
<td>3.879</td>
</tr>
<tr>
<td>Tow 2</td>
<td>2.378</td>
<td>0.073</td>
<td>2.584</td>
</tr>
<tr>
<td>Tow 3</td>
<td>0.197</td>
<td>0.018</td>
<td>0.189</td>
</tr>
<tr>
<td>Tow 4</td>
<td>1.421</td>
<td>0.057</td>
<td>0.239</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beam Trawl</th>
<th>Number of Nephrops Caught in each tow</th>
<th>Beam Trawl</th>
<th>Number of Nephrops Caught in each tow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Female Pale</td>
<td>Female Medium</td>
</tr>
<tr>
<td>Tow 1</td>
<td>224</td>
<td>6</td>
<td>296</td>
</tr>
<tr>
<td>Tow 2</td>
<td>189</td>
<td>16</td>
<td>200</td>
</tr>
<tr>
<td>Tow 3</td>
<td>17</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Tow 4</td>
<td>109</td>
<td>11</td>
<td>18</td>
</tr>
</tbody>
</table>
Figure 1. The positions of all sampling events during the Aran UWTV survey 2007. The UWTV stations are shown as numbered ‘+’s, SVPs are shown as red dots, beam trawls are the blue lines and CTD stations as green ‘x’ s. The boundary of the ground is annotated as a red line.
Figure 2. Scatter plot comparisons on inter-reader counts on a minute by minute basis. The red line indicates perfect agreement and the black line is a lowess smoother.
Figure 3. Box plots of the minute by minute burrow density estimate for the Aran grounds 2006.

Figure 4. A comparison of the estimated mean density of burrows for each station versus the mean of the minute by minute burrow density estimated for the Aran grounds 2006.
Figure 5: Burrow density distributions for the Aran Grounds by year from 2002-2006.
Figure 6: Omnidirectional mean variograms for the Aran Grounds by year from 2002-2006.

Figure 7: Cross validation plots for the Aran Grounds by year from 2002-2006.
Figure 7: Contour plots of the krigged density estimates for the Aran Grounds from 2002-2006.
Figure 8: a) Multibeam back scatter data for the Aran Grounds survey in 2005 and 2006. b) A zoomed in section of the multibeam data showing rocky outcrops around the boundary of the ground.
Figure 9. The bathymetry of the Aran grounds
Figure 10. Contour and post plots of the a) mean size (phi) and classification based on the Friedman & Sanders (1978) scales and b) sorting ($\sigma_g$) of the sediments on the Aran Grounds based on PSA results from samples collected from 2002-2006.
Figure 11. The relationship between *Nephrops* burrow density and various sediment variables collected during the 2006 Aran survey. The red lines are lowess smoothers and the blue numbers are correlation coefficients.
Figure 12. The CTD data collected during the Aran Ground survey in 2006.
Figure 13. A summary of the Nephrops biological data collected: length frequency distributions by haul, box plots of mean size by macroscopic maturity and haul and a maturity ogive for female Nephrops.
Figure 14. a) The monthly landings from FU 17 and survey abundance index b) mean standardised long term (1995-2006) seasonal trend in landings for FU 17 and c) the relationship between landings for two time periods and survey abundance estimates.