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Abstract

The *Nephrops* fishery on the Porcupine Bank takes place on a large area, approximately 7000km^2, of complex muddy habitat between depths of 300 to 470m. Irish effort has been increasing and Ireland is now responsible for the majority of the landings. The scientific advice has indicated that the stock has declined and fishing mortality should be reduced to the lowest possible level. This Irish Fisheries Science Research Partnership (IFSRP) survey was developed in 2010 to address the pressing need for data from the closed area established by the EC between 1st May to 31st July 2010. 46 hauls were carried out and the results indicate high CPUE for the survey relative to recent observations for the fleet. Strong patterns in size and sex ratio were observed spatially. The male biased sex ratio and size-at-maturity are similar to historical observation. The size distributions of the catches are very different to the Spanish survey in the area which took place two months later. The utility of the survey for monitoring the stock is discussed.

1 Introduction

The *Nephrops* fishery on the Porcupine Bank takes place on a large area, approximately 7000km^2, of complex muddy habitat between depths of 300-470m. The fishery typically yields very large individual *Nephrops* that attain very high market prices relative to other fisheries around Ireland. International landings from the fishery peaked in the early 1980s around 4000 tonnes but have shown a declining trend since then, despite some fluctuations (Figure 1). Landings-per-unit effort for both the Irish and French fleets also shows a long-term declining trend. Although the absolute stock size is uncertain, the stock is likely to be close to, or at, the lowest levels observed based on stock indicators (ICES, 2010a). Effort and landings trends indicate that fishing mortality has been high since the early 2000s. Fishery-independent survey information indicated that recruitment to catches has been very weak or absent between 2005 to 2008, but catches in 2009 show some recruitment occurring. The size structure and sex ratio of catches and landings have shown large changes in the last few years affirming the current concerns about stock status (ICES, 2009).

In June 2009 ICES advised that *Nephrops* catches in 2010 from the Porcupine Bank should be reduced to the lowest possible level (ICES, 2009). Under management considerations ICES also pointed out that given the sedentary nature of *Nephrops* populations closed areas may be an appropriate management tool to recover the stock. On the 21st July 2009 a meeting took place between the Federation of Irish Fishermen (FIF) and Marine Institute scientists to discuss the status of the Porcupine *Nephrops* stock and possible management measures to conserve the stock for the future. There was widespread agreement between the fishermen present at the meeting that the stock status had deteriorated and something had to be done. The participants agreed that the FIF should develop proposals in collaboration with the Marine Institute, for new management measures. The management measure favoured by the industry was a seasonal closure of the entire *Nephrops* grounds during the peak fishing months of May, June and July.

This “Irish Industry Proposal” was further developed with other stakeholders at the North Western Waters Regional Advisory Council (NWWRAC) and put forward to the European Commission (EC). The proposal for closed areas and the supporting scientific information (Lordan et al. 2009) were evaluated by the EC’s Scientific Economic and Technical Committee for Fisheries (STECF) in November 2010 and a closed area was implemented from the 1st May to 31st of July 2010 through Article 11 of Council Regulation 23/2010 (EC, 2010). This closed area is show in Figure 2.

The need for further scientific investigation on the stock and monitoring of the performance of the closure was identified at the outset (Lordan et. al 2009). Initially direct stock size estimates using underwater television surveys was suggested but the resource limitations meant modifications to the UWTV system and dedicated survey time were not available in 2010. As an alternative an industry-science partnership survey was developed. The funding model used was as follows: Vessel cost would be offset by landing the catch but the vessel would fish a predefined number of stations within the closed area using a small mesh gear. The scientific personnel and analysis cost would be borne by the Marine Institute. The specific objectives of the survey were as follows:

- To obtain size and sex ratio data from at least 28 stations which have been allocated randomly to the four survey strata inside and outside the closed area.

- To investigate variability in different biological and fishery parameters such as size, sex ratio, female maturity and CPUE over time and space. Where possible making comparison to historical data.
- To examine the utility of commercial grading information to monitor the size and sex distributions also.
- To use a standard trawl with modified cod-end to potentially improve selectivity of smaller *Nephrops* (this was seen as important to look at the distribution of the recruiting year class identified in survey data in 2009).

Since this was the first survey of this type to be undertaken there was an adaptive element to the survey design.

2 Materials and Methods

2.1 Scientific Personnel

The survey was carried out with one scientist on board (DS). Scientific activities were facilitated by the crew of the vessel.

Name	Service area/Affiliation	Role
Dave Stokes	MI-FSS	Scientist in Charge
Colm Lordan	MI-FSS	Team Leader

2.2 Survey Plan

2.2.1 Survey design

The survey was to take place during an ostensibly routine fishing trip and therefore efforts had to be made to balance the financial constraints of a commercial fishing operation with the scientific accountability of the results.

Given the survey objective was to correlate *Nephrops* samples from inside and outside the closed area, the survey was defined using both the current closed area as well as a larger area based on *Nephrops* directed fishing effort derived from integrated VMS-logbook data (using the method proposed by Gerritsen and Lordan, 2011). To ensure areas of naturally low abundance could be confirmed along with areas of high abundance a good distribution of stations was aided by further stratifying the de-lineated open and closed areas into north and south, along the 52° 10' line to give a total of four survey strata. The spatial distribution of proposed random stations is shown in Figure 3.

Fishing occurs during daylight hours only and it was proposed to carry out 3 tows per day of approximately 5 hours each. This was deemed to be the limit before which significant commercial time would be lost with repeat shooting/hauling of the gear, while also satisfying the scientific need to pinpoint data to specific locations in the survey area.

It was estimated approximately 42 stations therefore would be achievable and as a result 45 potential sampling locations were allocated randomly over the survey area by GIS (ArcMap 9.3), proportional to the area of each strata. These were uploaded to the vessels Sodena chartplotter

for ease of use, and areas of clear ground as close to the sampling stations were selected for fishing.

2.2.2 Specific operations

Haul positions were selected based on prevailing tidal and weather conditions and also in reference to sample station requirements for the overall survey coverage.

Tow tracks were logged using one of the ships Sodena chartplotters and a note made of shoot and haul time, depth, latitude, longitude and mean door spread.

2.3 Equipment and system details and specifications

The vessel that undertook the survey was part of the polyvalent fleet, the Ocean Pioneer (Reg S45). A 22.4m vessel registered in the port of Skibereen. Gross tonnage 174t, 440Kw engine and a crew of six.

Trawling was undertaken with a 30 fathom twin double-bag prawn trawls. This had 4.8m of 80mm cover, with upper and lower wings 80mm/100mm respectively. The remaining trawl was 90mm, with an inner cod-end liner of c.73mm (internal mesh) to maximise the length distribution sampled, while keeping the impact on the commercial revenue from the trip at reasonable levels.

The ground gear was 8" disks with 4" spacers and the doors were Thyburøn Type 11 (80"). The warps were restricted by a chain strap the width of the stern at approximately 175fm.

2.4 Protocols used

After each haul a random sample was taken from the hopper prior to sorting of the catch for commercial grading. As the four cod-ends were emptied sequentially into the hopper after each tow, the catch was horizontally layered. Taking a sample vertically through the catch in the hopper from top to bottom should therefore provide a cross section through the 4 layers, one from each cod-end.

The prawn sample was separated into 4 fractions: Female i) Female-Pale ii) Female-Dark iii) Females with Eggs; and finally Males. Each fraction was weighed separately and the prawn carapace lengths recorded in an Access database via the Marine Institute's NEMESYS software. This was running in the fish room on a ruggedized laptop computer and measurements were recorded directly to database by means of a wireless digital vernier calipers.

Efforts were also made to assist with the commercial processing of the catch as routine practical methods and communication can often provide important insights possibly not envisaged by theoretical design. The grading, blast freezing and further glazing of the prawns was labour intensive, but produced a reasonably detailed and repeatable size classification. Prawns were categorized similar to Table 1, and packed into 3kg boxes. Some extra categories included just tails or small prawns at 40-50. Females were separated from the males and categorized as either small, medium or large. Large approximating to male grade 5-10 and small females to males of 20-30 (Figure 4).

Table 1. Commercial grades for male *Nephrops* used by MFV Ocean Pioneer during the Porcupine IFSRP survey July 2010.

Grade	Average No per kg Box	Average Wt(g) per Prawn
0-5	4 - 5	200
5-10	8 – 10	111
10-15	13 – 15	71
15-20	18 – 20	50
20-30	27 – 29	35
30-40	37 - 39	26

2.5 Analysis methods

Metadata for each haul and length data were stored in an access database. Biological measurements were stored in a NEMESYS Access database. Data analysis was carried out using GIS (ArcMap 9.3), R and excel.

3 Results

A total of 46 hauls were carried out during the survey the majority of fishing time was spent within the closed area (Figure 3, Table 2). Discard of *Nephrops* were negligible so catch ≡ landings. The spatial distribution of these hauls differed somewhat from the initial planned random stratified selection. This was for operational reasons as some of these tows were off the *Nephrops* grounds or in untrawlable areas. It is noticeable however, that the majority of effort was spent in the middle of the closed area with little effort spent towards the northern and southern part of the ground. Tow durations varied from 1 to 7.5 hrs with an average of 5 hrs. Durations under 5 hrs invariably related to concerns over gear damage.

Catch per unit effort in weight varied considerably from haul to haul with a modal CPUE of 60kg/hr of and an average of 56Kg/hr (Figure 5). The observed survey CPUE was substantially higher than the average CPUE of 27kg/hr reported for the entire Irish fleet in 2009 (ICES, 2010). The mean CPUE for the survey is plotted in relation to the range of CPUEs as box plots for the Irish fleet in May, June, July 2003-2009 in Figure 6. The shaded boxes represent the main distribution of the fleet data (1^{st} – 3^{rd} quartile) with the heavy centre line being the median. The dashed whiskers indicate the full range of the data. Where a shaded box overlaps the survey mean the observed CPUEs are not statistically significant from one another. This confirms that the observed CPUEs during the survey were similar to the highest observed in recent years. Slightly higher CPUEs were observed for tows in the middle of the day (Figure 7).

The sex ratio and size of the graded catches show a distinct spatial pattern (Figure 8 and Figure 9). Males predominated and show a tendency for increased size towards the south of the closed area, resulting in increased proportions of these grades (e.g. 0-5, 5-10 Males).

The length frequency distributions show considerable variation from haul to haul (Figure 10). The mean carapace lengths (CL) observed in the catches were 40.5 CLmm for males and 39.7 CLmm in females. This represents a slight decline from those estimated from the Irish fishery in 2009. There is a noticeable trend in the size structure of the catches with latitude. Towards the north (>52°25') 90% of the individuals measured ranged from 28-45 mm in carapace length. Whereas in the south (<52°00') 90% of the individuals measured ranged from 32-54 mm in

carapace length towards the middle of the ground. The size and sex structure was found to co-vary with a number of factors as follows (Figure 11);

- The proportion of males in the catch declined with increasing latitude, longitude and depth.
- CPUE declines with increasing proportion of males in the catch
- Mean Carapace length increases with proportion of males in the catch
- Mean Carapace length declines with CPUE, proportion of males in the catch, longitude, latitude and depth.

The male sex ratio in the catches overall was 74% by weight and 64% by number. The inter quartile ranges for individual hauls were 63-88% and 55-72% respectively. The time series of sex ratio of the landings from the commercial fishery is plotted over time in Figure 12 with the survey estimates included for comparative purposes. This shows that the male biased sex ratio observed on the survey is a more normal situation for this stock. The high proportions of female in the catches in 2008 and 2009 was an indicator of concern in the ICES assessment. Length-at-maturity is plotted in Figure 13. This shows a length at 50% mature at around 30 CLmm.

Subsequent to this IFSRP survey the Spanish Research vessel carried out a survey in September using a survey specific "baka" trawl. There is a significant difference between the length distributions of these surveys, for example a 4mm difference in the modal lengths. Figure 14 illustrates this difference graphically. The IFSRP survey caught significantly larger *Nephrops* than the Spanish survey suggesting significant gear, area or time related differences in the survey selectivity.

4 Discussion and Conclusions

The *Nephrops* fishery on the Porcupine Bank has become economically very important to several vessels in the Irish fleet in recent years. Participation and effort by Irish vessels in the fishery has increased rapidly since 2003 (Davie and Lordan, 2011 and ICES 2010) as has the Irish contribution to overall catch (Figure 1). The scientific information for this stock is relatively poor and there is an acceptance by scientists and industry that steps should be taken immediately to improve this situation. Currently the stock is mainly monitored using fishery dependent data; landings, effort and biological sampling of landings. There is an existing Spanish Porcupine Survey (2001-> present) that has become a very important source of fishery independent data on the stock. This pilot IFSRP survey was initiated to obtain more data for the stock, specifically during the 2010 closure, but as independent as possible of variable commercial fishing behaviour.

It is clear that the distribution of *Nephrops* in terms of both size and sex is not homogenous over the Porcupine Bank. This survey confirms previous observations made (Hillis and Geary, 1990) that smaller *Nephrops* were found towards the north east part of the ground. This result can partially explain the large size differences in the mean sizes in the landings of the different countries exploiting the stock (Figure 7.6.2 of ICES, 2010a). Landings data by rectangle reported to ICES for some years do show significant differences in the spatial origin of landings from the countries involved in the fishery. In the past Irish landings with smaller mean CL have tended to come from the north eastern part of the ground where smaller individuals were also found on the survey and CPUEs were generally higher. The French landings in the past with larger mean CL have mainly been from the south western part of the ground.

There is an inverse correlation between mean size in the catches and burrow density across a range of *Nephrops* stocks and also within stocks (Lordan, unpublished data). It seems likely

that burrow densities in the north eastern part of the Porcupine Bank ground are higher than in the middle or south western part of the ground. This is something that would certainly be worth investigating with UWTV surveys in the future. The different size structure is also a factor that needs to be borne in mind in the assessment of the stock since fishery dependent size indicators will be impacted by changing fishing behaviour (this can be easily monitored now using VMS). This study shows a negative correlation between proportion of males and latitude and increasing CL with proportion of males. The latter finding is as expected but is in contrast to the unusual findings of Hillis and Geary (1990) which showed the opposite. The trend in sex ratio may well be caused by differences in emergence behaviour between the sexes at different burrow densities or size/age.

The recent switch in sex ratio in landings and catches may be the result of over exploitation of the male component of the stock (ICES, 2010). Normally, mature female *Nephrops* moult once a year shortly after hatching of eggs in April or May. There is a 24hr period after moulting when the male *Nephrops* can mate with the female (Farmer, 1974). It has been suggested that insufficient males in the population to mate with the recently moulted females can result in a change in female behaviour whereby unmated females concentrated on feeding and growth instead of reproduction. This so called “sperm limitation” can result in the sex ratio changes observed in the Porcupine *Nephrops* in recent years although this has not been confirmed through sampling. A similar switch has also been observed in the Farn Deeps in recent years. The return to a more usual male biased sex ratio observed on the survey is a positive sign and may well be linked to the recent good recruitment. The L_{50} or length at 50% maturity observed during the survey is very similar to previous observations for Irish catches from this stock (Lordan, unpublished data) albeit slightly higher that was reported for Spanish catches (ICES, 2006).

Carrying out the survey on a vessel routinely fishing the area had several advantages. There was a good exchange of information for example about *Nephrops* and/or fishing behaviour in response to the tidal cycle. In stronger tides it appears fishing takes place on the smaller individuals in the north eastern part of the ground, towards the Porcupine Bite. During neap tides the potential is there to target the lower numbers of more valuable larger males in the south of the ground. The grading of commercial *Nephrops* catches is highly labour intensive and results in a quite definitive and repeatable size classification by sex. This has significant potential to provide reasonably detailed and reliable catch composition data retrospectively and on an ongoing basis which should be perused by the IFSRP.

One of the objectives identified at the outset of this survey development was the need to obtain information on the year-class recruiting to the fishery. The selectivity of the commercial gear was seen as an issue at the outset and a modified cod-end was used to improve the catch rate of smaller *Nephrops*. Clearly there is a large difference in the selectivity between this survey and the Spanish survey two months later (Figure 13). A combination of factors is probably responsible for this. The IFSRP survey was probably biased towards areas with better catches of larger *Nephrops* given the commercial imperatives. It may well be possible to correct for this bias through post processing of the data and exploring size distributions observed on the Spanish survey. There is also likely to be a large difference in selectivity between the ‘baka’ trawl and the commercial gear used on the IFSRP particularly in the belly and wings of the net. In advance of the survey the possibility of using an identical ‘baka’ trawl was discussed since the MI have some available. This was also ruled out as an option during discussions with the IFSRP due to concerns about compatibility (e.g. vessels, door, warps etc.) and the need for the survey to be commercially viable for the vessel involved. Finally there may also be an influence

of seasonal emergence patterns on the size structure of the catches. This was also discussed by the IFSRP and multiple surveys during the closure were suggested.

This survey has been useful from a scientific perspective both in terms of data collection and industry co-operation. However, it's utility as a fishery independent index will only be realised with multiple years of data and then only as an index of the adult stock. The survey results are not compatible with the on-going Spanish survey nor can we expect such a survey to be a useful index of juvenile *Nephrops* before they enter the fishery. The funding model used whereby all but the scientific staff cost were covered by the fishing vessel was the only way this particular survey could be carried out given the timelines and fiscal constraints. The limitations discussed above in terms of gear and control over areas fished needs to be considered by the IFSRP if future surveys are to be conducted. In particular a hybrid funding model might be developed compensating vessel for potential loss of earnings using a scientific gear or fishing in less economically productive areas.

Acknowledgements

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Table 2: Summary data of hauls made during the Porcupine IFSRP survey July 2010 on MFV Ocean Pioneer.

Haul number	Average Longitude	Average Latitude	Depth (m)	Average Time of haul	Haul Duration	CPUE (kg/hr)	Mean Carapace Length (mm)	Proportion male by weight	Raised Nos Male	Raised Nos Fem
1	-13.69	51.73	441	18:48	05:37	61.4	39.9	0.68	1553	2214
2	-13.70	52.06	431	08:28	05:16	46.7	38.9	0.66	3143	1405
3	-13.60	52.11	419	14:14	04:56	129.5	41.4	0.52	5749	5411
4	-13.59	52.29	393	20:19	03:38	93.3	39.4	0.70	4969	2085
5	-13.62	52.22	415	08:31	05:27	67.2	42.4	0.52	3002	2790
6	-13.51	52.24	426	14:03	04:34	96.6	41.3	0.50	3948	3729
7	-13.88	52.25	403	19:19	05:21	70.1	39.7	0.71	5509	2115
8	-13.45	52.28	438	08:47	06:05	61.6	40.1	0.52	4065	3289
9	-13.44	52.30	415	15:09	04:42	81.1	41.1	0.52	3507	3202
10	-13.77	52.21	397	20:08	03:44	44.2	43.8	0.98	2190	40
11	-13.75	52.22	393	08:05	03:54	64.6	44.3	0.55	1882	1460
12	-13.61	52.24	397	15:05	04:49	89.1	40.2	0.59	4859	3395
13	-13.49	52.17	405	18:23	05:00	60.0	42.5	0.62	2949	1707
14	-13.81	52.27	391	08:43	05:53	63.2	40.1	0.62	4355	2692
15	-13.45	52.38	397	14:43	04:53	54.1	38.7	0.68	3810	1980
16	-13.57	52.34	398	20:10	04:11	86.1	37.8	0.69	5939	2859
17	-13.62	52.24	416	08:56	05:39	36.1	41.3	0.79	2797	730
18	-13.59	52.22	417	14:51	04:21	74.5	40.9	0.65	3859	2062
19	-13.86	52.09	408	20:40	05:14	68.8	43.1	0.69	3189	1848
20	-13.82	52.24	406	09:47	07:30	25.6	41.6	0.89	2693	371
21	-13.72	52.13	406	18:23	06:47	57.9	42.3	0.71	4455	1666
22	-13.77	52.09	408	11:47	06:09	93.7	41.4	0.78	7146	2116
23	-13.78	52.08	409	18:55	06:27	50.7	43.4	0.84	3724	734
24	-13.73	52.07	424	08:35	05:50	58.1	41.3	0.82	4863	1006
25	-13.64	52.15	421	14:38	04:53	73.1	41.2	0.84	5155	885
26	-13.76	52.10	409	20:05	04:05	30.1	43.2	0.85	1408	274
27	-13.85	51.91	408	08:27	05:18	55.5	39.3	0.88	5303	679
28	-13.87	52.40	416	14:24	05:21	66.2	39.0	0.92	6615	596
29	-14.01	51.73	403	19:20	03:08	35.4	41.1	0.92	1648	187
30	-14.09	51.59	437	07:56	06:58	22.8	44.8	0.94	1710	162
31	-13.92	51.82	401	14:39	04:50	45.3	40.7	0.92	3446	357
32	-13.98	51.84	397	18:25	01:10	64.3	40.5	0.92	1205	123
33	-14.09	51.69	401	08:39	05:16	29.1	41.6	0.88	1900	407
34	-13.89	51.82	415	15:02	04:56	68.1	38.7	0.92	6251	607
35	-13.85	51.84	441	20:31	04:56	23.1	41.9	0.92	1589	148
36	-13.83	51.75	463	08:48	05:38	8.5	46.8	0.88	347	119
37	-13.76	52.01	437	15:24	05:18	40.2	41.5	0.93	3279	266
38	-13.68	52.21	400	20:40	03:52	23.3	42.8	0.96	1197	49
39	-13.34	52.42	432	08:44	05:42	29.5	39.1	0.75	2435	1047
40	-13.08	52.64	471	14:12	02:12	174.5	36.8	0.54	4953	4904
41	-12.80	52.74	482	20:17	04:43	50.2	37.9	0.64	3335	2244
42	-13.04	52.64	463	09:42	07:15	53.4	37.9	0.48	4125	4983
43	-12.76	52.74	486	18:32	07:22	72.9	37.0	0.60	7963	5538
44	-12.71	52.76	464	08:51	05:32	24.9	32.6	0.64	3241	2237
45	-12.42	52.60	475	14:50	04:36	40.4	32.5	0.83	5650	1251
46	-12.27	52.43	494	19:59	04:06	8.8	35.2	0.64	469	409

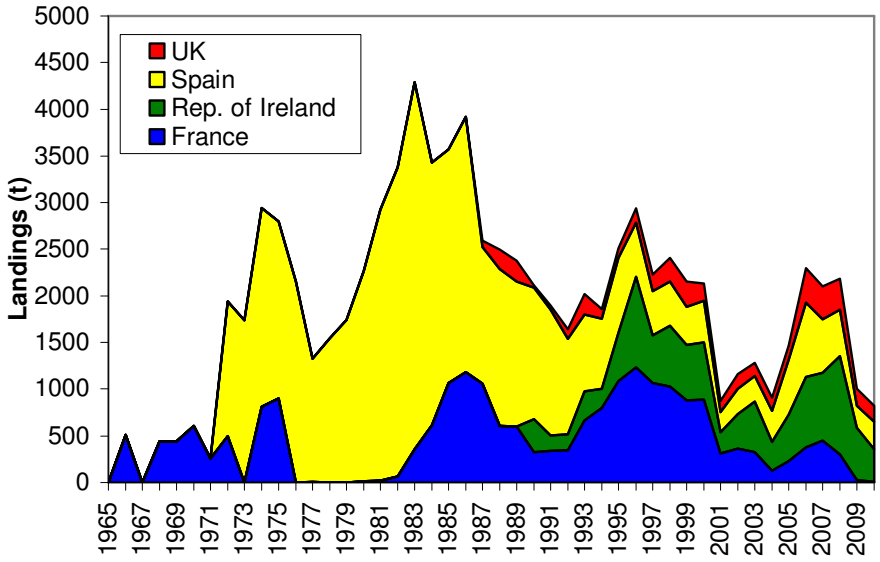

Figure 1. Landings in tonnes by country of *Nephrops* from the Porcupine Bank (FU16). Annual landings are stacked on top of each other.

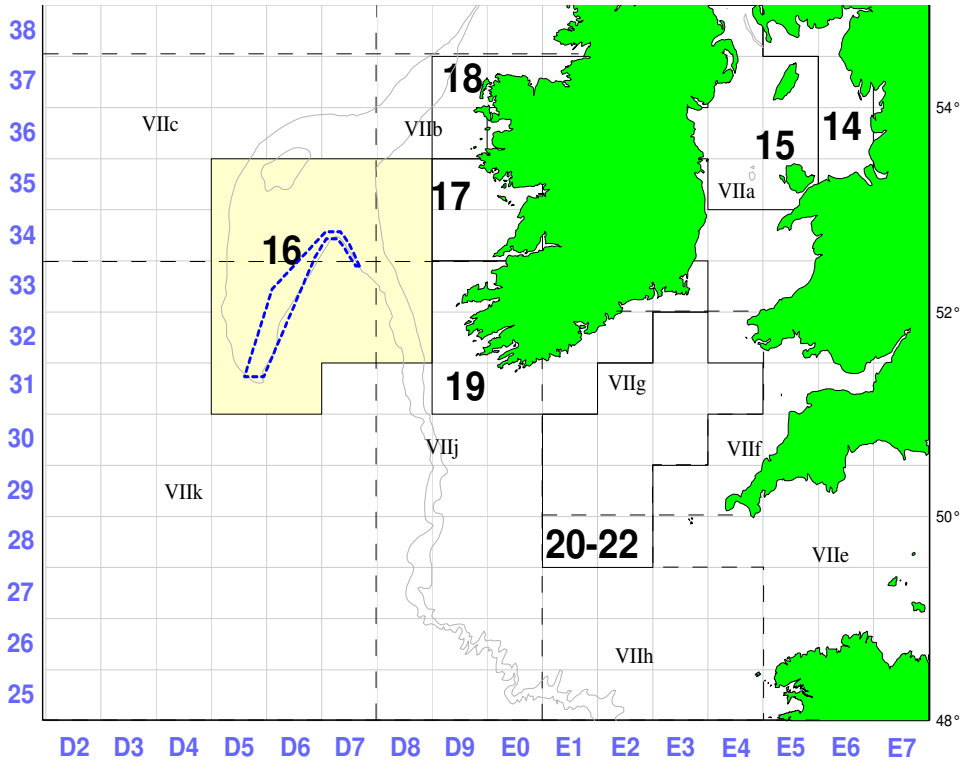

Figure 2. The closed area to all fishing (except pelagics) implemented between 1 May-31 July 2010 on the Porcupine Bank (FU16).

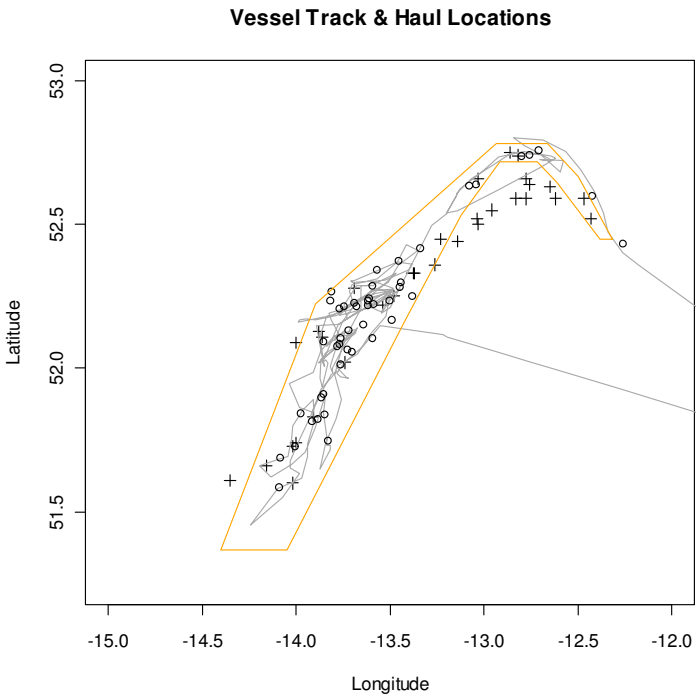

Figure 3. Plot of MFV Ocean Pioneer track (grey line) during the Porcupine IFSRP survey July 2010, proposed random stations (+) and mid points of completed hauls (o) are also shown.

Figure 4. Showing prawns graded commercially into 3kg cartons. From the left of the picture at the front we see an example of female grade 'small'; then male grade '15-20'; female 'medium' and finally male '5-10'.

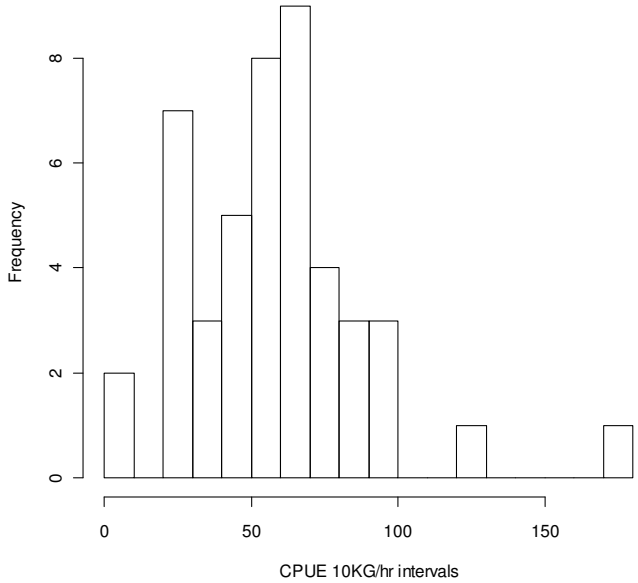

Figure 5. Frequency distribution of catch per unit effort for sampled hauls.

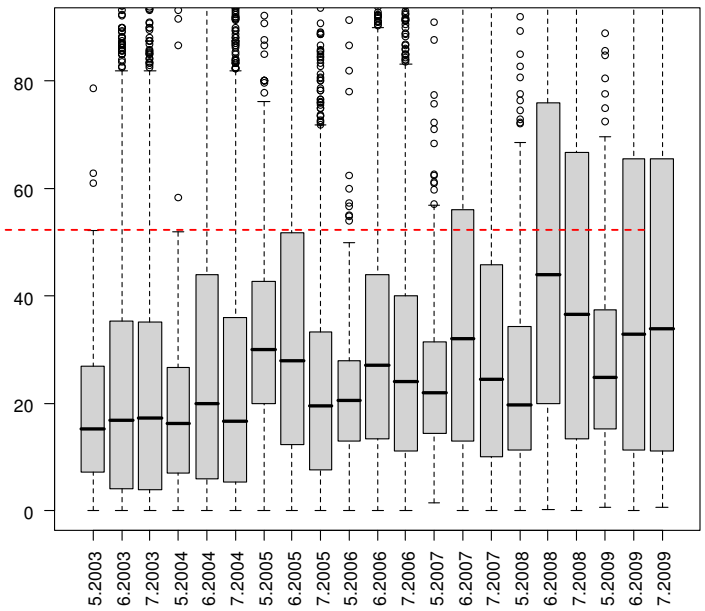

Figure 6. Box plot of daily CPUEs for the Irish fleet on the Porcupine Bank during May, June and July 2003 - 2009 together with the average CPUE observed on the survey of 56KG/hr shown as the red dashed line.

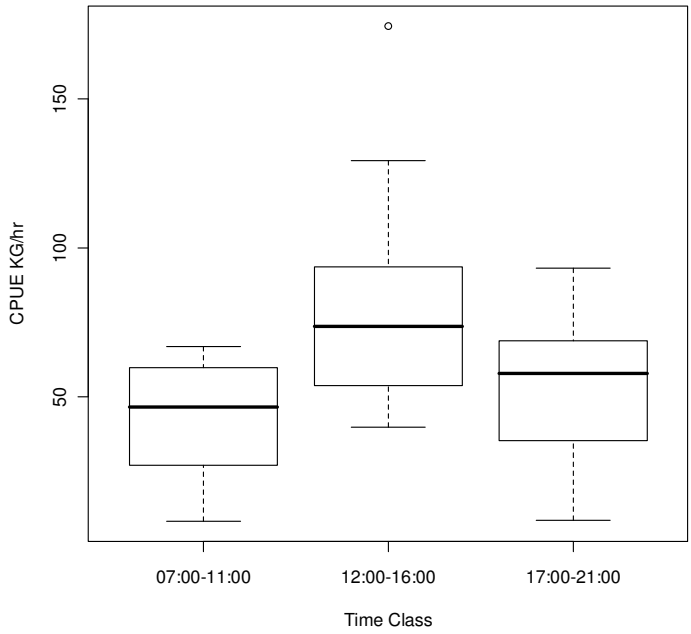

Figure 7. Box plot of catch per unit effort for hauls made at different times of day.

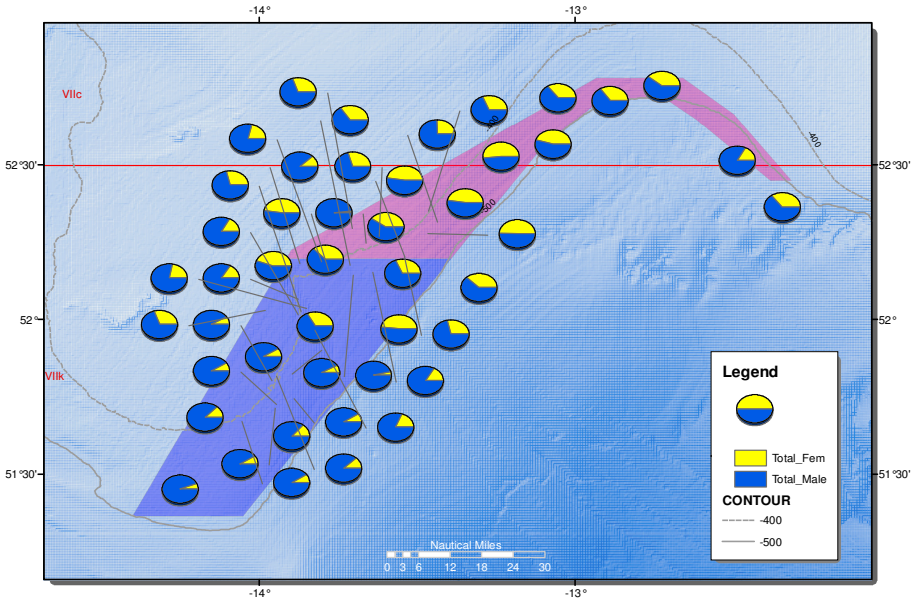

Figure 8. Pie charts of sex ratio of male and female *Nephrops* catch weight by station during the Porcupine IFSRP survey July 2010.

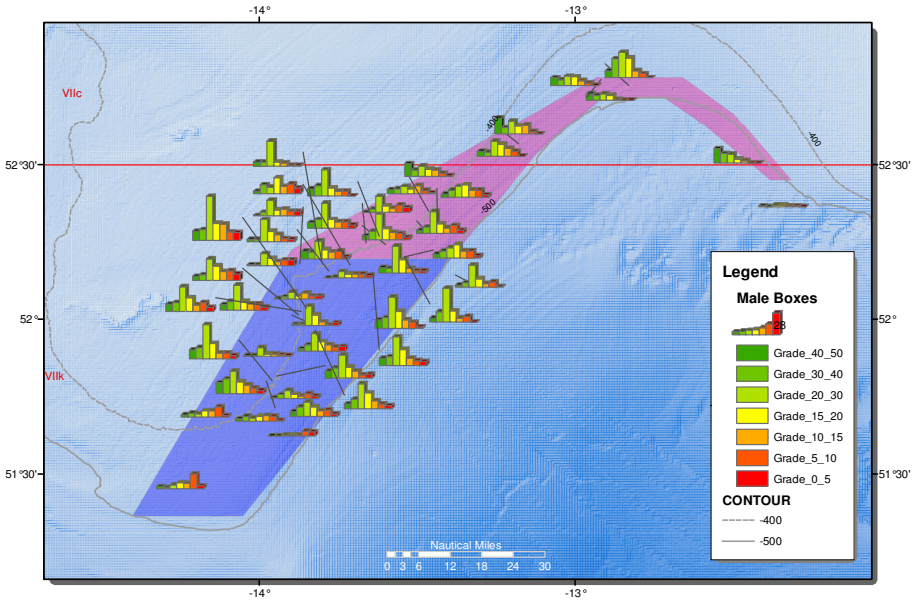

Figure 9. Bar charts of the proportion of male *Nephrops* catch weight by grade and by station during the Porcupine IFSRP survey July 2010.

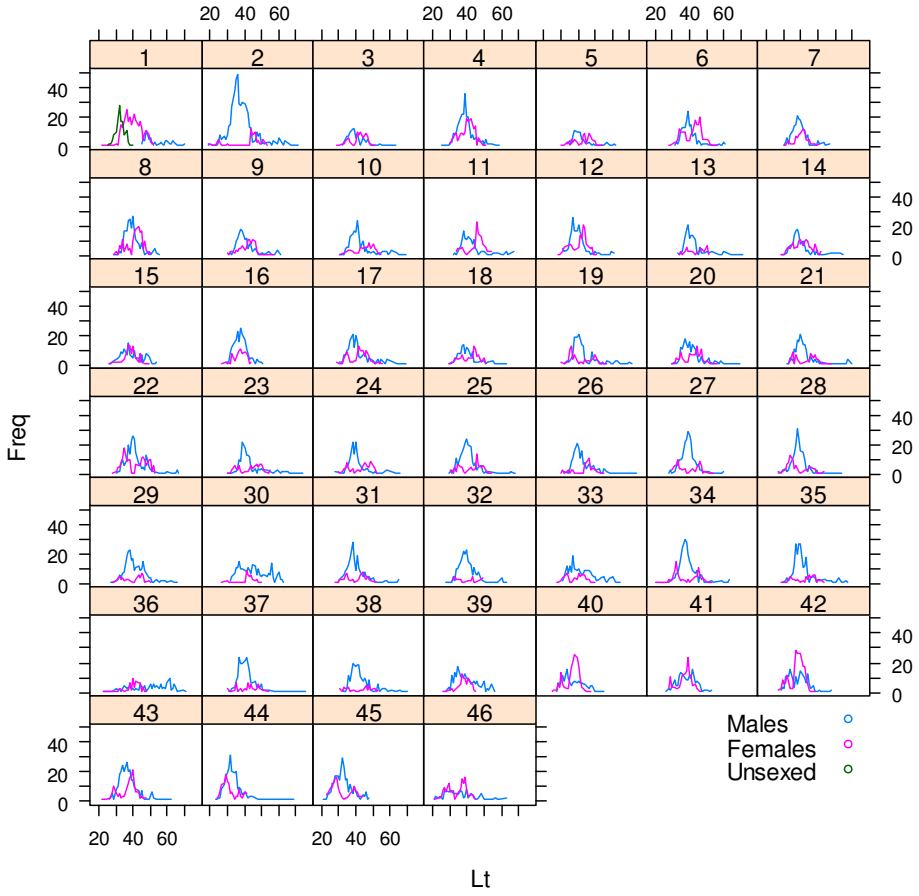

Figure 10. Length frequency distributions for individual hauls during the Porcupine IFSRP survey July 2010. (After the first hauls all catches were sexed).

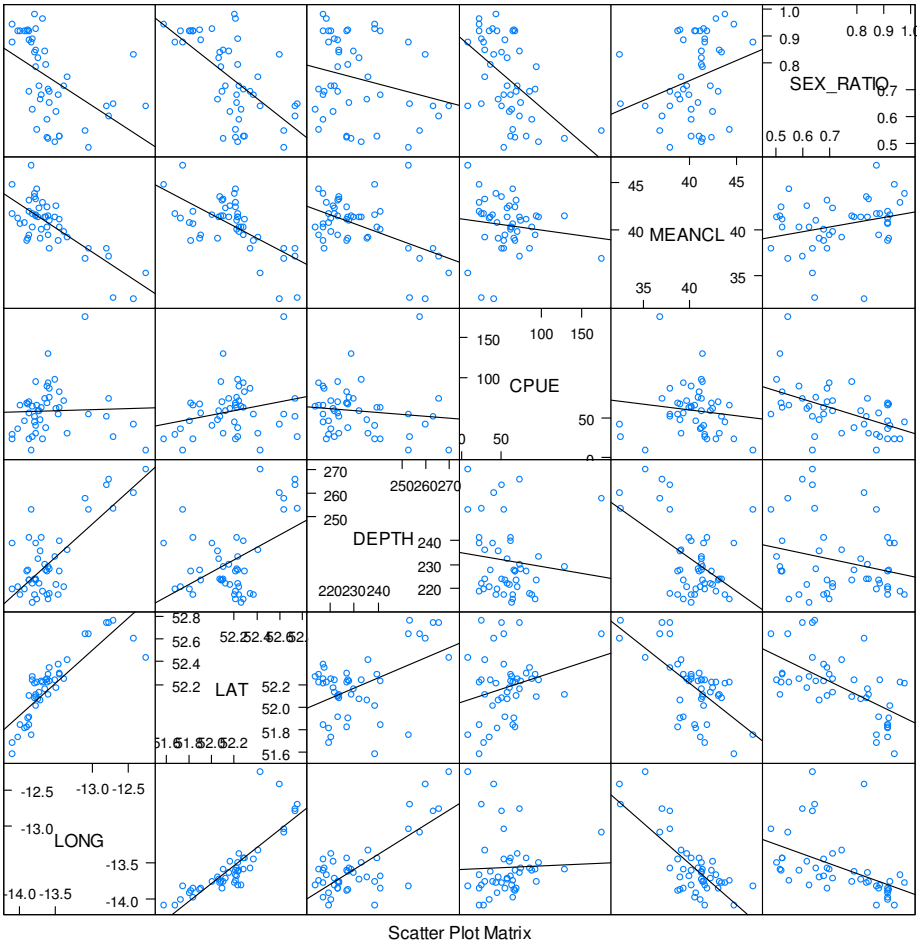

Figure 11. Exploring relationships between various variables collected on the Porcupine IFSRP survey July 2010.

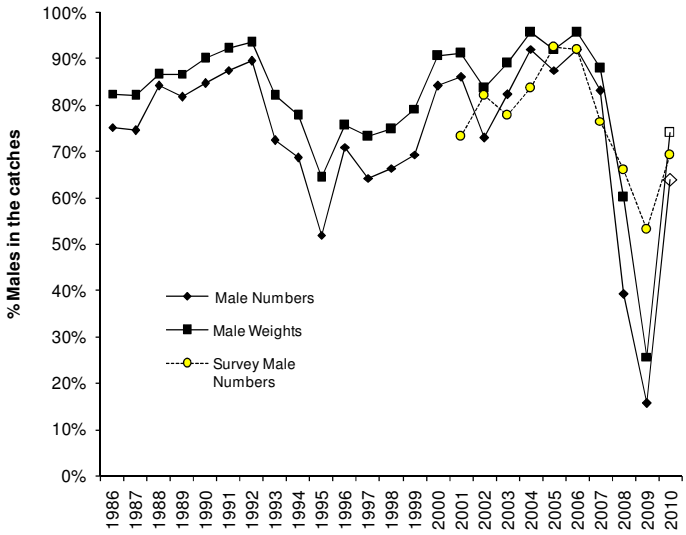

Figure 12. Time series of the percentage males in the catches for the international fleet and the Spanish Porcupine survey. The 'open' 2010 data points are for the Porcupine IFSRP survey July 2010 only.

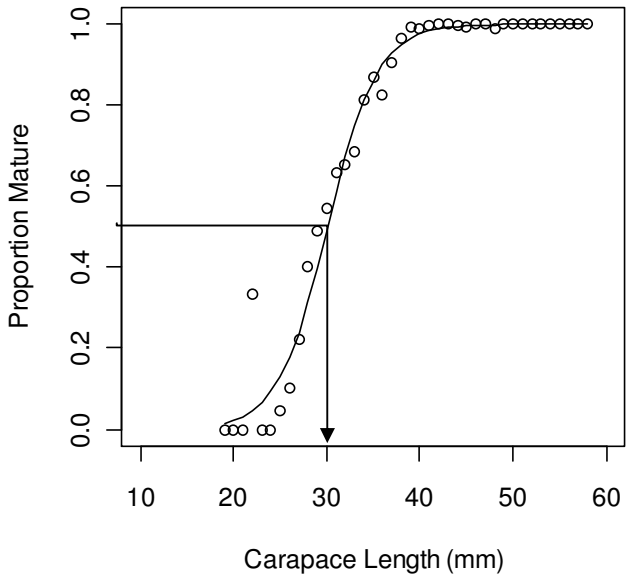

Figure 13. Maturity ogive at length for sampled female *Nephrops* during the survey showing a length at 50% maturity around 30mm CL.

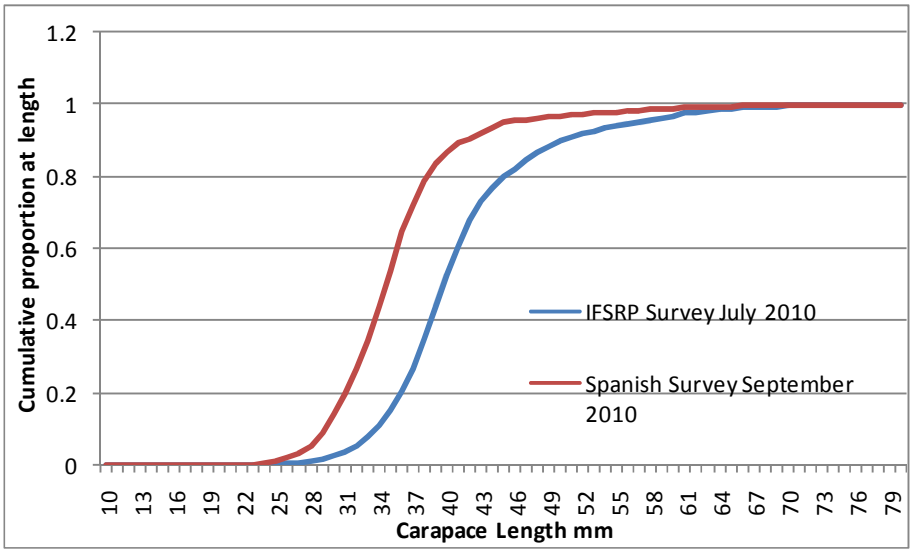

Figure 14. Plot of the cumulative length distributions for the Irish the Porcupine IFSRP survey July 2010 and the Spanish survey September 2010.

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