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Workshop on the Use of UWTV Surveys for Determining Abundance in Nephrops Stocks throughout European Waters

17–21 April 2007

Heraklion, Crete, Greece

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

The first ICES workshop on the use of UWTV surveys for determining abundance in *Nephrops* stocks throughout European waters took place in Heraklion, Crete from 17–21 April 2007. There were 19 participants from 12 different countries and laboratories and included ICES observer countries of Greece and New Zealand. There was considerable pre-meeting preparation with 9 full working documents and 15 presentations made, providing invaluable material with which, to focus discussion and draft the report. All of the diverse ToRs were addressed by the group at the meeting. Considerable progress was made in a number of areas and key areas for future work were identified.

The first objective was to document activity, equipment, methods and procedures in use in the various laboratories. The estimated total landings of *Nephrops* in the Northeastern Atlantic and Mediterranean are around 60kt. In 2006 annual surveys were carried out on grounds or stocks which account for 63% of the total *Nephrops* landings. A further 17% of the average landings have been covered by previous UWTV surveys or will be covered in the near future by planned experimental surveys. Detailed information on the equipment and specification used by the various laboratories is detailed in section 3.

The various survey designs in use were reviewed in section 4. These include stratified random sampling based on available sediment distribution maps and randomized fixed grid designs. Both methods seem to give comparable results although there has been little work to date to examine the statistical advantages of either approach or to optimize sampling design. Work carried out at the meeting suggests that there may be considerable saving in effort by altering sampling design.

Survey methodologies are discussed in section 5. Most countries have detailed standard operating procedures for their surveys already, so the discussion focused on differences rather that the standard approaches. Counting procedures and methods are in general very similar between most laboratories. An experimental approach to investigating the internal and external consistency of burrow counting is advocated and results should be transparently documented. There was also some work to suggest that tow duration or the counted fraction of the tow could be reduced, saving man-power, but this would need further confirmation on a case by case basis. The key issues of quality control, assurance, and data management were discussed. Most laboratories have frameworks in place to insure the integrity of their surveys. Calibration and training are seen by the group to be areas that will need to be addressed in the future by another workshop focusing specifically on that issue. It is recommended that such a workshop be convened by ICES in 2008.

Translating the survey results into abundance estimates and using them in assessments or in the provision of management advice is discussed in sections 6 and 7. This has relevance to ICES Working groups and ACFM. The main conclusion was that there are assumptions and potential biases in the surveys. These would need to be addressed and minimized particularly if the survey is used in an absolute sense to estimate abundance. Using the survey to estimate absolute biomass is not likely to be accurate due to uncertainty about mean size in the burrow-forming population.

The surveys do perform very well as a relative indicator of abundance compared with other surveys methods used in fisheries work (i.e. trawl and acoustic). Ideally the surveys should be used to calibrate an assessment that also uses fisheries dependent data i.e. landings, discards, effort and length or age structure. In many *Nephrops* stocks accurate data are not available due to misreporting, discarding, and limited sampling. In their absence the current approach advocated by some assessment WGs of using a harvest ratio based on the abundance estimate from the survey may need further work addressing some of the accuracy and bias issues, particularly edge effects and occupancy. Assuming these can be solved then the 20% harvest

ratio can be considered a reasonable starting point for deriving a harvest ratio based catch. The simulations however, assume perfect TAC implementation and similar catch size distribution in the short-term. The harvest ratio may need to be adapted in the future depending on observed stock response.

Finally, because they do not migrate very far from where they settle as juveniles, there is a strong link between *Nephrops*, the ecosystem, and their fisheries. UWTV surveys are ideal for studying benthic habitat and therefore this method has advantages from the perspective of studying both the benthic habitat and *Nephrops* stocks.

1 Agenda

1.1 Terms of Reference

A Workshop on the use of UWTV surveys for determining abundance in *Nephrops* stocks throughout European waters [WKNEPHTV] Took place in Heraklion, Crete from 17–21 April 2007. Chair: Colm Lordan (Ireland).

Terms of Reference:

1) Review and report technological developments used in underwater TV surveys for *Nephrops*.
2) Compare survey designs employed in different areas and evaluate, where possible, the relative performance of these.
3) Report on work addressing outstanding issues influencing the accuracy and precision of TV estimates of abundance *inter alia* burrow identification, occupancy rate, counting method, survey data analysis, raising procedures.
4) Document the protocols used to conduct surveys across the range of European stocks, highlighting standard practices and 'norms' adopted in UWTV work.
5) Investigate and make recommendations on procedures for inter-calibration, quality assurance and the reporting of precision from TV surveys.
6) Report on developments in the translation of survey estimates into stock assessment information and catch forecast advice, recommending where additional work is most urgently required.
7) Consider the wider utility of the techniques employed in *Nephrops* UWTV surveys for estimation of other benthic species and habitat assessment.

1.2 Participants

A full list of participants and contact details for those whom attended the meeting is given in Annex 1.

NAME	COUNTRY
Jim Atkinson	**Scotland**
Ewen Bell	**England**
Richard Briggs	**Northern Ireland**
Neil Campbell	**Scotland**
Helen Dobby	**Scotland**
Jennifer Doyle	**Ireland**
Jon Elson	**England**
Spyros Fifas	**France**
Francisco Leotte	**Portugal**
Colm Lordan (Chair)	**Ireland**
Sten Munch-Petersen	**Denmark**
Heye Rumohr	**Germany**
Cristina Silva	**Portugal**
Chris Smith	**Greece**
Nadia Papadopoulou	**Greece**
Ian Tuck	**New Zealand**
Mats Ulmestrand	**Sweden**
Adrian Weetman	**Scotland**

1.3 Working documents

Below is a list of the Working Documents presented to the meeting. The full text of these working documents is given in Annex 2.

1) Using UWTV in crustacean trawl surveys, as a tool for *Nephrops* stock assessment. F. Leotte and C. Silva.

2) Report of the UWTV Survey on the Aran, Galway Bay and Slyne Head *Nephrops* Grounds 2006. Colm Lordan, Jennifer Doyle, Fabio Sacchetti, Deirdre O'Driscoll, Imelda Heir, Turloch Smith and Chris Allsop.

3) Modelling *Nephrops norvegicus* burrow densities from the Western Irish Sea Annika Mitchell and Richard Briggs.

4) FRS *Nephrops* TV Survey Design. Neil Campbell and Adrian Weetman.

5) FRS Protocol for Establishing a *Nephrops* Burrow Abundance using Under Water Video. A. Weetman and N. Campbell.

6) Deriving appropriate harvest rates for the *Nephrops* stocks around Scotland Helen Dobby.

7) Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1) and Wiararapa / Hawke Bay (SCI 2). I. Tuck and A. Dunn.

8) Automating counting of Norway lobster using underwater video analysis. Paulo Lobato Correia, Phooi Yee Lau, Paulo Fonseca and Aida Campos.

1.4 Presentations

Day one and half of day two were dominated by presentations of prepared material to the group. Below is a list of the various presentations made:

1) Pilot study: Underwater TV surveys for *Nephrops* in Kattegat and Skagerrak. Bo Sølgaard Andersen and Sten Munch-Petersen, DIFRES, Denmark.

2) CEFAS *Nephrops* TV Survey. Jon Elson, CEFAS, UK.

3) CEFAS counting analysis: intra-lab consistency and tow duration. Ewen Bell, CEFAS, UK.

4) Comparison of different methods for estimating *Nephrops* densities. *Nephrops* fishery VIIIab (Bay of Biscay). Verena Trenkel, IFREMER-Nantes, modified and presented by Spyros Fifas, IFREMER-Brest, France.

5) A summary of Irish *Nephrops* UWTV surveys – equipment, methods and data. Jennifer Doyle, Marine Institute, Ireland.

6) A review of the Aran *Nephrops* UWTV surveys. Colm Lordan, Marine Institute, Ireland.

7) Modelling *Nephrops norvegicus* burrow densities from the Western Irish Sea. Annika Mitchell, Queen's University of Belfast and Richard Briggs, Agri-Food and Biosciences Institute, Northern Ireland.

8) Scampi surveys in New Zealand. Ian Tuck, NIWA, New Zealand.

9) Preliminary evaluation of underwater television (UWTV) as a fishery-independent method for stock assessment of Norway lobster, *Nephrops norvegicus*, in the central Adriatic Sea. Betulla Morillo and Carlo Froglia, CNR-ISMAR, Sede di Ancona, Italia and Jim Atkinson, UMBS Millport.

10) Technology utilized by FRS in Estimating *Nephrops* norvegicus Burrow Abundance. A. Weetman and C. Shand, FRS, UK.

11) FRS *Nephrops* TV Survey Design. Neil Campbell, FRS, UK.

12) FRS Data Process. Neil Campbell, FRS, UK.

13) Deriving appropriate harvest rates for the *Nephrops* stocks around Scotland. Helen Dobby, FRS, UK.

14) Use of UWTV sledge in Greece, by Christopher Smith and Nadia Papadopoulou, HCMR, Crete, Greece.

2 Introduction

The first experimental UWTV surveys were carried out by Scottish scientist in the early 1990s. In the last 15 years there has been a proliferation in the number of surveys, countries, methods, design and usage of UWTV surveys for *Nephrops*. Increasingly ACFM and STECF are using the information from surveys as the basis of management advice for stocks where surveys exist (ICES, 2006, STECF, 2006). Despite the ever increasing survey effort there has been very little formal attempt to review or coordinate UWTV surveys through ICES, in contrast to what is normal with other survey inputs used in the assessment process (e.g. trawl or acoustic surveys). This workshop was the first opportunity to discuss and document the evolution of the various surveys, the equipment, methods used and to progress many of the key issues associated with the methodology. The main objective was to improve the transparency of the method by describing and discussing the method, the problems and assumptions properly. The second objective was to improve future surveys by establishing best practice and progress their utility by making recommendations on future design, methods, standardization, training and usage in assessment.

Underwater television or photographic surveys are ideal methods for surveying and assessing *Nephrops* stocks. *Nephrops* is a mud-burrowing species that is protected from trawling while within its burrow. Burrow emergence is known to vary with environmental (ambient light level, tidal strength) and biological (moult cycle, females reproductive condition) factors. This means that trawl catch rates may bear little resemblance to population abundance. In addition, growth is known to vary considerably even within stocks and estimation of the age distribution of the stock or catches not readily achievable due to ageing problems. This makes tradition age based assessments problematic. *Nephrops* are closely linked to suitable habitat. They construct recognizable and countable burrow complexes. They are highly territorial and probably do not move more than a few hundred meters over their lifespan. This means that UWTV surveys designed to track burrow abundance on the suitable habitat should be very good indices of stock development. The task of an UWTV survey is relatively simple compared that with pelagic or demersal surveys which attempt to track relative abundance of highly mobile species in three dimensions often with variable performance of sampling gears.

The spatial distribution of the main *Nephrops* stocks and fishing grounds around Europe are shown in Figure 2.1. Stocks in the Northeast Atlantic are numbered according to the previous ICES Functional Units (FUs) see ICES (2002). The spatial distribution of stocks and fisheries in the Mediterranean is not a well documented or no developed *Nephrops* fisheries exist (e.g. Libya and other North African countries). Stocks where annual or experimental surveys have taken place or are planned for the near future are shaded. A summary of the status of UWTV work on the various stocks is shown in Table 2.1 together with recent estimates of landings and the relevant assessment or management area.

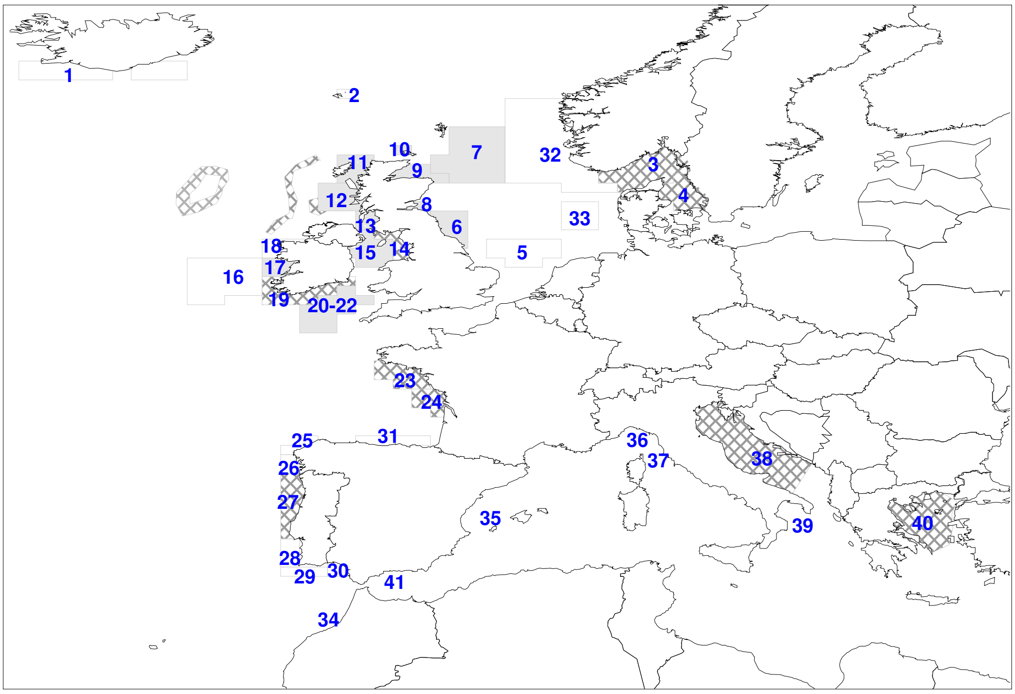

Figure 2.1. *Nephrops* stocks and fishing grounds in European waters. Stocks and grounds with annual *Nephrops* UWTV surveys is shown in filled grey and areas with experimental or planned surveys are indicated with hatched grey.

In the North Sea annual UWTV surveys now cover stocks that account for approximately 77% the total landings from the IIa and IV TAC areas. In the west of Scotland the annual surveys now cover stocks that account for 97% of the VI TAC and experimental surveys are carried out in deeper waters along the shelf, at Rockall and on the Stanton Banks. Around Ireland annual or planned experimental survey cover stocks that account for 86% of the landings from the VII TAC. The time-series of *Nephrops* surveys in VII is relatively short. The estimate total landings of *Nephrops* in the Northeastern Atlantic and Mediterranean are around 60kt. In 2006 annual surveys were carried out on grounds or stocks which account for 63% of the total *Nephrops* landings. A further 17% of the average landings have been covered by previous UWTV surveys or will be covered in the near future by planned experimental surveys.

Table 2.1. *Nephrops* reported landings by fishing area and stock (averages for 2000–2002), and countries taking most of the landings. A= annual surveys, E= exploratory surveys, PE: planned exploratory surveys for the near future.

Functional Unit	Fishery or Stock Area	ICES Divisions	TAC Area	Average Landings kT (2003-05)	UWTV Survey	Years with Survey	Used in assess. or man.
1	Iceland South coast	Va		1.40			
2	Faeroe Islands	Vb		0.10			
3	Skagerrak	IIIa	IIIa; EC waters of IIIb,	2.33	PE		
4	Kattegat	IIIa	IIIa; EC waters of IIIb,	1.59	PE		
5	Botney Gut - Silver Pit	IVb,c	EC waters of IIa and IV	1.06			
6	Farn Deeps	IVb	EC waters of IIa and IV	2.50	A	1997, 1998, 2002-2006	Y
7	Fladen Ground	IVa	EC waters of IIa and IV & Norwegian waters of	8.57	A	1992, 1993, 1995, 1996, 1998-2006	Y
8	Firth of Forth	IVb	EC waters of IIa and IV	1.59	A	1992,1994, 1996, 1998-2006	Y
9	Moray Firth	IVa	EC waters of IIa and IV	1.34	A	1992, 1994-1996, 1998-2007	Y
10	Noup	IVa	EC waters of IIa and IV	0.24	A	1994, 1999, 2005 & 2006	Y
32	Norwegian Deep	IVa	Norwegian waters of IV	1.05			
33	Off Horn Reef	IVb	EC waters of IIa and IV	1.04			
	Other areas in the North Sea	IV		1.13			
11	North Minch	VIa	VI; EC waters of Vb	3.13	A	1994, 1996 1999-2006	Y
12	South Minch	VIa	VI; EC waters of Vb	3.86	A	1995, 1996, 1998-2006	Y
13	Clyde	VIa	VI; EC waters of Vb	3.21	A	1995, 1996 1999-2006	Y
	Other areas in VI	VI		0.36	A & E		
14	Irish Sea East	VIIa	VII	0.47	E		
15	Irish Sea West	VIIa	VII	7.02	A	2003-2006	Y
16	Porcupine Bank	VIIb,c,j,k	VII	1.48			
17	Aran Grounds	VIIb	VII	0.74	A	2002-2006	Y
18	Ireland NW coast	VIIb	VII	0.02			
19	Ireland SW and SE coast	VIIg,j	VII	0.98	A	2006	Y
20-22	NW Labadie, Baltimore and Galley	VIIg,j	VII	4.67	A	2006	Y
	Other areas in VII	VII	VII	0.19			
23	Bay of Biscay North	VIIIa	VIIIa, VIIIb, VIIId and	3.23	E	2004	
24	Bay of Biscay South	VIIIb	VIIIa, VIIIb, VIIId and	0.35	E	2004	
25	North Galicia	VIIIc	VIIIc	0.08			
31	Cantabrian Sea	VIIIc	VIIIc	0.02			
26	West Galicia	IXa	IX and X; EC waters of	0.03			
27	North Portugal (N of Cape Espichel)	IXa	IX and X; EC waters of	0.03			
28	South-West Portugal (Alentejo)	IXa	IX and X; EC waters of	0.38			
29	South Portugal (Algarve)	IXa	IX and X; EC waters of	0.00			
30	Gulf of Cadiz	IXa	IX and X; EC waters of	0.22			
Number	**Fishery or Stock Area**	**FAO Area**	**GFCM Management Unit**	**Landings kT (2005)**	**UWTV Survey**	**Years with Survey**	**Used in assess. or man.**
34	Morocco Atlantic coast		n/a	0.30			
35	Catalan Sea	FAO 37.1.1	6	0.50			
36	Balearic	FAO 37.1.1	5,4	0.10			
37	Alboran Sea		1,2	0.10			
38	Ligurian and N Tyrrhenian Sea	FAO 37.1.3	9,10	0.70			
39	Adriatic Sea	FAO 37.2.1	17,18	1.80	E	?	
40	Ionian Sea	FAO 37.2.2	19	2.00			
41	Aegean Sea	FAO 37.3.1	22	0.40	E	1996, 1998, 1999	
Average Landings ('000 t) of all Nephrop stocks (2003-2005)				60.30			

Nephrops is absent form the Baltic Sea, the Bosporus, the Levantine Sea and the Black Sea. In the Western Atlantic and indo-west Pacific, there are a number of species closely related to *Nephrops* within the genus *Metanephrops*. Reported annual landings for most of these (e.g. *M. mozambicus, M., andamanicus*, or as *Metanephrops* spp as not all species are recorded by species name) are in the order of 100 t or less. No regular assessments, trawl or UWTV surveys are available for these species. The only exception is *Metanephrops challengeri* with landings form New Zealand in the region of 1000 t. Three *M. challengeri* stocks have been regularly monitored with trawl surveys and a variation of the UWTV method using high resolution stills (see Section 4.1.6 for a description of technique and 7.3 for stock assessment method).

3 Survey systems and technology

3.1.1 A review of systems in use

3.1.2 Brief description of Sledge

UK-FRS

FRS uses a sea grade aluminium frame measuring 1.5 m (H) x 2.1 m (L) x 1.6 m (W), with sacrificial skids, and 6 mm holes drilled though out the frame to reduce buoyancy (Figure 3.1.1 and Figure 3.1.2.) Electrical equipment is held in clamps which in turn are clamped to the frame. Items located on the sledge include: a forward facing colour Kongberg Simrad zoom video camera; two Kongsberg Simrad miniature underwater halogen lamps; an odometer; a 35 mm Benthos camera and synchronized flash; a Remontec Range Finder (which provides data on distance to the seabed, sledge depth and distance travelled); a sonar transmitter; lead acid batteries housed in an aluminium tube (to power the rear camera, Benthos camera and flash); a mini van Veen sediment grab; and two 12V high torque motors (one for the van Veen and one to raise and lower the odometer) (Table 3.1.1.) At the rear of the sledge, a set of connector 'tails' run from a fixed bulkhead connector to each electrical item.

UK-CEFAS

The Cefas sledge used for the *Nephrops* underwater TV surveys was adapted from one constructed for scallop and habitat surveys (Figure 3.1.3). The original structure was altered in 2005 to open up the framework at the front. This allows a camera to be mounted forward of the Cefas standard position at an angle more acute to the seabed and at a sufficient height to be in line with the set up of FRS, AFBI and MI standard *Nephrops* TV surveys.

The sledge is constructed of welded sea grade aluminium tubing with steel sacrificial runners. Fixed aft and within the frame is a sliding, swinging mount for the standard camera. The other camera is fixed to a bracket braced between parallel stanchions towards the front of the main frame.

The size of the sledge and set up for the 2006 Farn Deeps survey is shown in Figure 3.1.4. The items shown in the diagram include two Kongsberg Simrad zoom video cameras; four Seatronics high intensity LED lights individually controlled at the surface through a PC interface; an odometer; a laser scalar array constructed of four boresight parallel lasers to calibrate the field of view for the forward camera; an Applied Acoustic Engineering transponder used as a beacon for the HIPAP positioning system (used to provide an estimate of distance run). All powered systems except the HIPAP beacon are supplied and controlled from the surface through a steel double armoured Rochester tow cable terminated and fed through a junction box at the front of the sledge. Video data from the standard camera is transferred through the single coax in the tow cable, signals from the second camera, in this instance, were transferred through a twisted pair using a Balun EV Offshore booster (Table 3.1.1).

The link between supporting shipboard and sledge systems are provided in the flow diagram Figure 3.1.5.

UK-UMBSM

UMBSM uses an aluminium sledge built to the Shand and Priestley (1999) specification. An Osprey (Kongsberg-Simrad) colour TV camera (OE1362 or OE1360) is the camera usually used, but a Kongsberd Simrad monochrome camera (OE1366) may also be used (Table 3.1.1). This camera has good IR capability for behavioural work. The frame will also accommodate older Hydroproducts SDA and monochrome cameras and lights but these are now rarely used. The sledge is provided with a Hasselblad mounting to house an FRS camera. UMBSM does not have a digital still camera on the sledge but is currently investigating options, including upgrading the TV cameras. Illumination is provided by two Versabeam 500W lights (Remote Ocean Systems). These can be fitted with IR filters (fittings manufactured in-house) if required for behavioural work. Two 300W Kongsberg-Simrad lamps are also available if required for fill in. Normally only one of these is used.

The sledge has an odometer to the FRS design but without motor deployment of the odometer arm. The UMBSM vessel RV Aora (22 m,ca.300 t) is provided with a 37-channel split-ring winch that handles 27 mm Kevlar cable to the FRS specification. The vessel has 400 m on the winch drum, but the drum can accommodate 600 m. Control is from the electronics laboratory with bridge override. UMBSM also has non-armoured cables of various lengths that can be lashed to the tow warp of other vessels.

IR-MI

Marine Institute Ireland sledge is based on the "Aberdeen" design- and is approximately 1.8 m wide*2.4 m long *1.5 m tall and 80kgs (Figure 3.1.7). It is fitted with 3 fishing buoys to ensure upright position during deployment. Also a buoy with an appropriate rope length is attached to the sledge to aid in recovery. The light units (2 x Kongsberg-Simrad OE11–135 300 watt halogen bulb) are bracket mounted at the front bar of the sledge and point directly downwards (Table 3.1.1). The video camera (a Kongsberg-Simrad OE14–366 colour zoom) is mounted at an angle of approx 45° in an adjustable bracket (30–65°) fitting as shown in Figure 3.1.7. The MI also has a digital stills camera (OE14–108) so an additional sleeve insert has been made so that both cameras can be mounted on the one mounting.

The main difference between the MI and CEFAS and MARLAB systems is that the cable used (NC-13) is a non-load bearing cable. The sledge is towed on a load bearing wire and the camera umbilical is attached at 10 m interval with cable ties. This is considerably cheaper option since it does not require a slip-ring winch. It has limitations in terms of the number of channels and power available on the sledge and requires a lot of manual intervention during deployment and retrievals. An IXSEA GAPS acoustic transponder head unit is attached to the top bar and the associated battery unit is tied down to the back saddle as in Figure 3.1.8.

A schematic showing the integration of the various hardware, sensors, software and the final data outputs on a typical UWTV survey is given in Figure 3.1.9. Further detail on sensor integration, specifications etc. are given in Lordan *et.al.* WD 2. Typically for each deployment the navigational data logged is linked to the DVD recording of the video footage by haul number and time stamp. No screen overlay is used. There have been previous experiments with a "geo-referencing video capture system" developed by the National Centre for GeoComputation (NCG) in Maynooth and future development of the system is planned for 2007.

UK-AFBI

The sledge used by AFBI for Northern UWTV surveys is a modified version of the FRS sledge (Shand and Priestly, 1999) and has proved to be durable and robust. The sledge is fitted with floats on top to help maintain an upright position during deployment. A buoy is attached to an appropriate length of rope (at least twice the operational water depth), which is attached at the rear of the sledge to aid retrieval in the event of entanglement, and to provide a drag force, which reduces the yaw of the sledge. The system cameras and use is described in the AFBI- Procedural Guideline No. 3–14.

D-IFM-GEOMAR

An Aberdeen type aluminium sledge (“decapitated”)is used both as towed and hanging device for video and photo sensors (Photo: TVP and CAMEL) A small detachable steel sledge for air transport is used in shallow waters.

DK-DIFRES

The sledge used by DIFRES was originally built by IMR-Sweden. It is based on similar design of FRS “old” sledge (Shand and Priestly, 1999). A fishing-buoy is arranged in the top to maintain the sledge in correct position. Currently, the sledge is equipped with two lights (ROS, QL3000) and a video camera (ROS, INSPECTOR) (Table 3.1.1). The arrangement of the equipment is very similar as described in Shand and Priestly (1999). Currently, the sledge is towed with a 12 mm trawl warp, where the electronic cable from the camera and lights are attached with plastic strips (around every 10 meters). The cable has a total length of 475 m and a diameter of 14 mm with 17 cores, and an internal Kevlar braid bearing around 700kg. The cable is stored on a hand witch drum with a 16 channel split-ring. A transportable winch drum with hydraulic system is under construction so in near future the sledge will be towed only with the Kevlar cable.

GR-HCMR

The HMCR video sledge used is a modern Marine Laboratory (Aberdeen) design (Shand and Priestly, 1999). Until very recently the camera was an Osprey (OE1362 Osprey Electronics, Aberdeen) low light sensitive colour camera, mounted on the sledge looking obliquely forward with two wide angle 500 W underwater lighting units (Versabeam, Deep Sea Power and Light, Aberdeen) (Table 3.1.1). The camera has a fixed focal length lens and a wide field of view of one metre. The sledge is towed from the research vessel on a trawl warp (12 mm) to which the electrical cables of the camera and lights are attached by quick release ties (soft un-armoured umbilical). Floatation is added to the warp at the sledge end of the cable to help keep the towing cable from disturbing the sediment in front of the sledge. Camera with data (time, date, run and elapsed time functions) is controlled through a Cyclops control unit (Osprey, Aberdeen). Video recording is undertaken in the S-VHS format.

The system has just been upgraded with a new 600 m soft umbilical cable and camera system. The camera system is a Tritech ISS/VMS wide angle camera with zoom, five lasers and focus controls. An interface box has been constructed to run-off the previous Cyclops control system. Lighting has been changed to two 2wide angle HID lights with integral ballast (Deep Sea Power and Light, Aberdeen). The sledge also now has a forward-looking scanning chirp sonar (Tritech Micron sector scanning sonar). The cable terminates in one plug and is connected to a pressure-cased junction box with separate plug connections for the lights, camera, scanning sonar and ancillary port. Recording is now undertaken on the surface through a DVD recorder, either on hard disk or DVD disks. The recorder has the facility for time code input.

3.1.3 Drop frames

UK-FRS

FRS uses an aluminium drop frame, suspended directly below the stern of the vessel, to observe grounds with a rough terrain (that may damage the sledge) or has potential objects on the seabed that may get entangled with the sledge (creels for example). All the same equipment is found on the drop frame as the sledge, except for the odometer (but the ship’s navigational data provides accurate positional data for distance travelled). The cameras are mounted vertically instead of obliquely as with the sledge, at a height of approximately 1 metre off the seabed. This provides a smaller field of view than the sledge, and objects pass through the field of view far more quickly. However, the drop frame is very susceptible to weather conditions, with any lift in the rear of the vessel being transferred directly to the frame, and the vessel is drifting when using the drop frame, coverage is at the mercy of the wind strength and direction.

UK-UMBSM

A steel-construction drop frame can be operated from the same winch as the sledge. Thus the equipment mounted on the sledge can also be mounted on the drop frame. The drop frame is normally rigged with one Kongsberg-Simrad colour camera and two Versabeam lights. Several other drop frames are available for special applications.

NZ-NIWA

Scampi surveys in New Zealand are conducted by NIWA using a self contained drop frame system, deployed on a trawl warp, with a vertically mounted digital still camera and an obliquely mounted flash to provide illumination contrast. Camera timing is controlled by an in-house timing card, with images recorded to a compact flash card, and downloaded via USB connection at the surface. A netsonde unit is mounted on the frame, and winch control is adjusted to maintain camera altitude at approximately 4 m above the seabed. Two parallel red lasers (200 mm apart) are mounted vertically on the frame, and image area is calculated by digitization of the recorded image and distance between the lasers. A full system description are operating instructions are available on request.

DK-DIFRES

DIFRES has not used a drop frame for *Nephrops* studies. However, DIFRES has developed several different types of drop frames for other specific purposes (e.g. sediment structure for sandeels, behavioural studies of flatfish, estimation of mussel coverage and abundance, etc.). These dome frames are normally rigged with similar camera and light set-ups as used for the sledge.

3.1.4 Trawl mounts

UK-FRS

Although there has been considerably work using trawl-mounted cameras within the Marine Laboratory to look are fish and gear behaviour. These systems have not yet been applied to a *Nephrops* specific application.

UK-UMBSM

UMBSM does not use trawl-mounted cameras for *Nephrops* work, but has camera clamps that have been fitted to other types of fishing gear in the past.

D-IFM-GEOMAR

Trials with a SIT camera mounted to a shrimp trawl have previously been used to analyse the catching process. Cameras were mounted on runners and on a mono-sledge just in front of the groundrope rollers.

GR-HCMR

In 2007 HCMR will take delivery of a remote camera system deployable on trawl or lander. The camera has a low light black and white camera, integrated recorder and batteries (recorder with hard disk and time lapse function), separate heavy duty battery for 24 hour deployments and lights.

PT-IPIMAR

Combining UWTV with trawl surveys is the easiest way to collect video footage at depths greater than 350 m. This is particularly useful as the Portuguese *Nephrops* stocks are distributed from these depths down to around 850 m, thus rendering the use of ROVs or towed camera systems connected to data cables, highly impractical. For this purpose, IPIMAR opted for the use of an autonomous video recording unit attached to the trawlnet at the centre point of the headrope, as shown in Figure 1. The camera is deployed pointing forward onto the seafloor at an angle of approximately 45º to obtain footage of a fraction of the gear path, typically 1/27 of total path width. The autonomous camera, lighting and video recording unit are contained within a reinforced metal frame of small dimensions (43 x 30 x 12 cm).

DK-DIFRES

Currently, no camera system has been used in *Nephrops*-trawls. However, currently a new low light camera system (ROS NAVIGATOIR, lux 3.4 10^{-4}) with integrated hard-disk (memory cards) and batteries is under construction for studying the behaviour of the *Nephrops* and other demersal fish species within the trawl.

3.1.5 Suspended frames and gliders

FR-IFREMER

A Sony PD 150 colour video camera (34° opening angle) was mounted perpendicular to the sea floor on the towed body. One 400 Watt light projectors was fixed behind the camera.

3.1.6 Creel frames

UK-FRS

In 2005, FRS constructed a steel frame that was capable of housing a video camera, flash card recorder, batteries and two infrared lights. A traditional D prawn creel was suspended in the middle of the frame and clearly viewed by the video camera. This frame has been deployed on a number of occasions, and the baited creel has attracted a variety of fauna, which has been recorded on video. The footage collected clearly shows the range of species attracted to the creel, the interaction between individuals, and the way they interact with the creel; most interestingly being that very few individuals of commercial species that approach the creel are caught.

GR-HCMR

In 2006, HCMR constructed a steel creel frame (very similar to that of UK-FRS). The system was used on a number of occasions to film baited creels, using the video sledge camera system but with other cameras (colour CCD, colour CCD with lasers, low light SIT), same cable, red-filtered lights, same control system.

DK-DIFRES

The Danish Creel fishery for *Nephrops* is almost non-existent, primarily due to the lack of suitable creel fishing habitats in Danish waters. Therefore, no Creel frames have been used for *Nephrops* or other species.

3.2 Main and additional uses for the described UWTV equipment

UK-FRS

The sledge is used on three *Nephrops* TV surveys: East Coast of Scotland; Fladen and the West Coast; and the West Coast Sea Loch survey. Around 330 TV runs are completed annually using the sledge for the purposes of *Nephrops* abundance estimates. The sledge is also used by FRS for habitat mapping at the shelf edge and benthic observation work around outlet sites. Feasibility trials have begun to investigate the practicality of using the sledge off the seabed to observe monk fish populations. Recently, by removing most of the electrical equipment usually associated with the sledge, several water samplers have been mounted on the sledge which was then towed behind a trawl, to investigate benthic disturbance when fishing.

UK-CEFAS

As well as the *Nephrops* UWTV surveys, Cefas use the UWTV sledge to look at anthropogenic impacts e.g. dredging and aggregate extraction; to look at ecosystem health (benthic quality assessment) and for seabed and habitat mapping (see Section 8.3). The shipboard systems and general setup will be similar for most of these the surveys, but one of the video cameras will be replaced with a stills camera.

UK-UMBSM

In addition to enumerating *Nephrops* burrows as part of research projects the sledge is used to film biota on a wide range of grounds. This includes work on habitat mapping and on the impact of fishing gear on various grounds. As a university institution, UMBSM has a major teaching function: exercises involving underwater TV on various grounds are a component of this.

IR-MI

This main use of the UWTV system is used to determine *Nephrops* abundance in the commercially important *Nephrops* grounds off the Irish Coast. Three surveys are conducted currently on an annual basis: Irish Sea West (Functional Unit 15), Celtic Sea (FU 20–22) and Aran Grounds (FU17).

Additional uses of the system include: a project mapping scallop grounds off the Southeast coast of Ireland, ground-truthing of seabed mapping projects and other uses focused on habitat mapping.

UK-AFBI

The equipment has been used to perform an UWTV survey of the western Irish Sea (Division VIIa) *Nephrops* grounds (FU15). These surveys are preformed jointly with the Irish Marine Institute and have been completed annually since 2003 (4 surveys to date). In addition to this task the equipment has been used in a range of broad scale benthic mapping projects off Northern Ireland and beyond.

FR-IFREMER

In the *Nephrops* fishery of the Bay of Biscay, there was no specific survey until recently. In 2006, a *Nephrops* directed trawl survey was initiated. No current UWTV video survey is carried out for this fishery. However, the UWTV methods were also explored (2004) on six sites of the central mud bank of the Bay of Biscay (depth 80–100 m) at the aim of analysing daily variations of *Nephrops* catchability.

NZ-NIWA

The system was developed in the late 1990s, and has been modified since its first routine use in 1998. Given the generally greater depths of scampi grounds in New Zealand, compared with those where video systems have been used in Europe, a drop frame system was considered more appropriate. The vertically mounted still camera, combined with generally good seabed water visibility result in a relatively large image footprint (typically average 7

m^2), minimizing any edge effects, and allowing burrow and animal measurements to be taken without consideration of perspective.

D-IFM-GEOMAR

Baltic Monitoring sine 1986 and work in North Sea (IMPACTI and II Project) Benthos image profiles on routine stations and depth profiles in the Baltic.

DK-DIFRES

DIFRES started last year (2006) building a technical setup for applying an UWTV survey for *Nephrops* in the Kattegat and Skagerrak. Currently, the equipment is being tested, and practical experience is being gained. A technical set-up has been specifically designed for UWTV survey in shallow waters (<150 meter), to be operated on a relative small research vessel, and with the flexibility to be re-rigged on different types of vessels. The plan is to conduct an UWTV survey in the Kattegat/Skagerrak in 2007.

GR-HCMR

The sledge has been extensively used for other purposes mainly in research projects for general area survey, but in particular for the investigation of the seabed impacts of trawling (Coggan *et.al.* 2001, Smith *et. al* 2000). The sledge has also been equipped to stimulate the impacts of a trawl groundrope with samplers built into the frame including water bottle for sampling resuspended material and hyperbenthic nets set at different heights above the seabed (Dounas, Koulouri *et.al.* 2003).

PT-IPIMAR

This system was initially set up for the purpose of counting *Nephrops* and their burrows, yet this particular system can be used for different kinds of work including general epifaunal studies (i.e. study into other species' abundance, behaviour in the presence of the trawl gear, etc.), estimation of bioturbation levels, trawl impact and disturbance levels on the seafloor, and trawl gear dynamics during operation.

3.2.1 Advantages for *Nephrops* related work

UK-FRS

As a fishery-independent method of stock analysis, potentially inaccurate landing figures have no bearing on the outcomes of this work. As this method is based on burrow complex counts, the effects of emergence patterns, animal reactions to the sledge and seasonal differences are not affected. Direct observations on animal behaviour can be made, as well as the potential for measuring from the video the size relationship between *Nephrops* claw size and burrow width.

The FRS sledge is the most advanced in use currently the main advantages is that the camera height, odometer distance and depth are all integrated together for each run (See WD 5). The mini-grab system also saves the time required to obtain sediment samples at each station by other means.

UK-CEFAS

The UWTV surveys provide a direct index of abundance unaffected by the seasonal and diurnal emergence behaviour of *Nephrops*. The abundance estimates are free of the uncertainties affecting analytical assessment methods such as inaccurate landings figures and dynamic pool assumptions.

IR-MI

This current camera and sledge system can be used on research and non-research vessels as the system is quite simple to set up and operate and is relatively low cost, since there is no requirement for a slip-ring towing winch. Despite considerable manual intervention required in attaching the umbilical to the towing cable during deployment, the system is relatively easy and fast to deploy and retrieve.

On the RV, an IXSEA GAPS (Global Acoustic Positioning System) has been employed since 2005 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; however during the UWTV surveys a single transceiver is mounted on the camera sledge. As in Figure 3.1.9 the various on-board navigational signals are bundled into Starfix Navigational Suite and the ship position, sledge position and layback are outputted as a text file for mapping the distance over ground. This has the main advantage that various comparisons can be made easily between all navigational data before choosing which should be used for the distance over ground calculation.

FR-IFREMER

As there is no interference with the ground, the towed body system is mainly advantaged because disturbance reducing visibility and edge effects are avoided. As the camera is mounted perpendicular to the sea floor, that implies no effect of the angle of incidence *in situ* and, hence, a more accurate estimation of the actual sampling unit.

DK-DIFRES

More practical experience is needed to with the system to evaluate any advantages, problems or limitation with the recently acquired technical equipment.

GR-HCMR

The *Nephrops* sledge work has been carried out under research projects, but may become part of the national monitoring programme. It has many advantages over trawling basically the results are less variable than those derived from trawling, although there is no information on individual sizes, sexes and therefore of population breakdown.

PT-IPIMAR

Due to its small dimensions and light weight, the autonomous self-contained unit is easily handled and deployed during the trawl operations. Transferring the images onto a PC is also a straight-forward and quick process using a common USB (UWTV-PC) connection, allowing a high turnover time between deployments. This procedure is, however, not strictly necessary after every tow, but useful if the position of the UWTV equipment and image angle need to be adjusted to improve overall image quality.

The technologically advanced power management unit (up to 10 hrs of battery time) and the increased data storage capacity (up to 30 hrs of video recording) offer the possibility for carrying out non-stop work if necessary.

3.2.2 Problems and limitations experienced

UK-FRS

Problems associated with the sledge include the costs involved (FRS insure the sledge for £50 000, cables cost around £20 per metre, cable terminations are £3 700, and spares and laboratory equipment amount to £4 000); weather limitations; fishing activity can obscure visibility and require stations to be resituated; and considerable time needs to be invested in training staff in handling the sledge and video interpretation. Reviewing the footage can have some associated problems, including: consistency in burrow identification for an individual and between reviewers; calculating the field of view; edge effects; towing speed can reduce the details observed; clarity of the water; weather induced motion; and pair reviewing biasing.

UK-CEFAS

Problems range from the costs of setting up the system through the data collection to the translation of the counts to abundance estimates.

Cefas insure the sledge and data logging systems at £55 000 (this does not cover the cable, winches and the ships navigation and positioning systems).

Data collection can be hampered by weather and fishing vessel activity. Both can cause turbidity in the water, which affects video quality. This limits the ability to correctly identify or even notice *Nephrops* burrow systems. Swell and waves will affect how well the sledge stays in contact with the seabed. Any lifting will affect the field of view and at its extreme the view can be clear of the seabed. Field of view estimates and distance run are vital to calculate the density of burrows. Uncertainties about these estimates are discussed in Section 6. Field of view for Cefas surveys is estimated just below the surface using a calibration screen and this estimate is applied to the counts at each station. Video footage from tows crossing or following a previous sledge track show that the sledge does settle into the sediment and evidence from FRS shows that the height of the camera from the seabed can vary considerably over a survey. Applying a real time estimate of field of view to account for this sinking as well as the lifting mentioned earlier could provide more accurate estimates of burrow density.

UK-UMBSM

The limitations of the system are that it does not have the level of sophistication of the systems used in the fishery institutes. Its advantage is that it is easy to deploy and maintain. RV Aora is fully compatible with FRS systems and has the same, identically wired bulkhead connector so the umbilical and split-ring winch will mate with FRS systems if required.

IR-MI

The addition of the USBL since 2005 has solved the problems concerning accuracy the distance over ground covered by the sledge. The main concern now is the accuracy of the field of view where the sledge maybe sinking or gliding above the seabed (as discussed above for the CEFAS system). Currently all the cores in the umbilical are used by the camera and lighting system this prevents the addition of sensors to measure camera height, roll and pitch, turbidity etc. or allow for the addition of a grab on the sledge. Also the current configuration using the non-load-bearing NC 13 cable only allows for the operation of one camera system at a time: i.e. either the video camera system or the digital camera system. Finally, deployment and recovery is laborious for the deck crew and there are concerns in terms of health and safety.

The Marine Institute is in the process of upgrading to a slip-ring winch, fibre-optic load bearing umbilical cable and associated topside and sub-sea equipment for the sledge-mounted underwater TV system. This will allow for multiple cameras (up to 3) and the addition of various sensors to calibrate field of view more accurately. The intention is that this system will be used for the shelf stocks (<200 m) a further deepwater system would be required for *Nephrops* grounds deeper than 200 m e.g. Porcupine Bank and shelf edge.

The system upgrade will improve the survey; however, a further problem occurs, mainly in the Irish Sea, where currents on the seabed are extremely strong. Here there are often problems with visibility affecting the ability to count burrows due to sediment in the water. To address the problem the survey is scheduled during periods of neap tides and often stations are visited on more than one occasion if the visibility is not good enough. There may also be technological solutions to the problems such as scanning cameras, cameras at multiple angles and video enhancement technologies (e.g. http://www.lyyn.com/). The intention is to investigate these once the new system is on-line.

The potential impact of weather is another is another potential limitation of any towed camera system. The sledge performs will up to wave heights of around 2.0 m. Poor weather in the Aran Grounds and Celtic Sea in previous years has impacted on the quality and quantity of footage obtained.

UK-AFBI

The main limitation with this system is knowledge of the exact position and track of the camera sledge and the field of view of the camera.

FR-IFREMER

For IFREMER the main concern is accuracy of burrow identification and the impact on density estimates. Burrows counts can be overestimated due to confusion with other species burrows (*e.g. Goneplax rhomboides*), uncertainty in identifying burrows belonging in a same system, unknown occupancy rate, and inter-reader variability.

NZ-NIWA

The system is useable in relatively poor sea conditions, and although large swell may result in the loss of many images (too close or too far from the seabed), increasing the duration of the deployment ensures sufficient useable images are recorded.

D-IFM-GEOMAR

The main concern is that the resolution is too poor for higher taxonomic ID at towing speeds around 1 kn; tow duration is normally 5–10 minutes.

DK-DIFRES

Limitation are currently: a) the rather small DIFRES research vessel (Havfisken) assigned to the TV surveys can only operate the sledge system in very good weather conditions; b) the relative high discharge of organic material in Kattegat, will often cause a high primary production, which causes high turbidity in the water column near the surface (specially in the summer period) and affects the video quality; and c) the number of electric cores in the umbilical limit the number of additional pieces of equipment that can be used on the sledge.

GR-HCMR

Limitations are the length of cable (depth of water), sea state in which work can be carried out (stability on the seabed), lifetime of the cable (ours is not armoured), quality of the video (range and resolution of the camera and blurring due to movement), even distribution of lighting on the seabed, penetration of lighting on the seabed, accurate size measurements, identification of burrows, and unknown occupancy rates.

PT-IPIMAR

Measurement accuracy

Image acquisition is done by means of frame-grabbing software. The selected video frames are then analysed using image processing software so that accurate measurement estimates of objects within the image can be extracted. As a means of maximizing measurement accuracy, the “Canadian Perspective” grid should be computed and subsequently superimposed onto the images. However, the lack of exact height parameters affects both the accuracy and precision of all measurements obtained from individual video frames. It would, thus, be useful to have time stamped information on the height of the UWTV equipment above the seabed.

Smear effect

Smear effect may also hinder image analysis. This effect occurs because the images are captured at speeds of around 2.8 knots (typical survey trawling speed). Nonetheless, placing the camera at +/- 1.8 m above the sea floor (average vertical opening of the crustacean trawlnet) and filming at an oblique angle, contribute to significantly reducing smear effect on captured images.

3.2.3 Improvements needed on current equipment

UK-FRS

FRS has equipped the sledge with many devices to minimize problems previously experienced in collecting and quantifying the data. The area that causes most concern is the reviewing stage, where correct burrow identification and burrow occupancy rates have a major influence in the final outcomes. Although FRS provides training and refresher courses for staff involved in TV surveys, variability between certain reviewers is noticeable on occasions. It is now recommended that a 10 minute sacrificial run is reviewed before final interpretation of footage is carried out; this helps the reviewer 'tune in' to the task before beginning on data that will be used in the assessments. Water clarity can have a major influence on the final counts, and FRS has introduced a key as to how to grade the clarity. This provides a quantifiable field when reviewer calibration work is carried out, and may help explain anomalous counts, but needs to be refined.

UK-CEFAS

To better calibrate this survey with other stock surveys around the UK a forward-looking camera has been fitted. Concurrent video needs to be collected from the standard forward-looking camera to calibrate future surveys with current time-series. The current cable only has a single COAX. Although a video signal was boosted through twisted pairs on the last survey, the quality was not good enough to accurately count burrows. Cefas is currently looking at replacing the steel armoured cable with a lighter Kevlar/polypropylene cable (dual coax or fibre optic). The weight of the Rochester cable does affect the warp to depth ratio -currently around 1.5 and often less. If more cable is paid out it drags in the sediment, which affects visibility. As the cable is so short the surface movement or lift is transferred directly to the sledge. If more cable could be paid out without disturbing the seabed then the vessels movement would become less apparent–the video data would be less disturbed by the sledge lifting and the field of view would be less variable.

Cefas has recently invested in a new Sony HCR-HD7 camera and housing. This will be mounted forward on the next survey and will only take power from the tow cable. With the current cable, video data will have to be downloaded *in situ*.

The laser array will provide a real time estimate of field width. Although there are not enough leads in the current tow cable to power an array for both cameras. In the short term, Cefas will review the possibility of sighting an altimeter at camera height to provide a better real-time estimate of field of view for the standard camera for the next survey.

IR-MI

As mentioned above the Marine Institute is in the process of upgrading the UWTV system to a full towing umbilical and slip ring winch using a load bear fibre optic cable and sub-sea multiplexing to allow integration with existing cameras and light systems. This new UWTV system will allow the capability to operate both the video and digital stills camera and improved field of view calibration. It will also allow for the capability to add further electronic units as UWTV technology develops.

There is a plan to mount a self powered and recording CTD sensor on the sledge to collect fine resolution oceanographic data during surveys.

In addition to improved data acquisition technologies there is considerable scope for improved data management and validation for UWTV surveys. This might be achieved by integrating the video, navigation and other datasets in a GIS framework which would allow quick data access and visualization.

UK-AFBI

There is a need to integrate an odometer and range finder to the AFBI sledge to improve the accuracy of the area viewed estimates.

NZ-NIWA

Future plans include an intention to fit a light meter to the frame.

D-IFM-GEOMAR

Future plans include putting a sensor package (Temp, Sal, O2).

GR-HCMR

For HCMR, immediate improvements could be made with a change to winch-mounted armoured umbilical. This would greatly reduce deployment and retrieval time. We would also consider replacement of the sledge system with an AUV system for large area measurements while the vessel could undertake some other work.

PT-IPIMAR

Fitting a self powered, time-stamped, good resolution altimeter onto the UWTV frame would solve the accuracy problem.

3.3 Minimum standards and requirements

Since this was the first workshop of its type it was only possible to aggregate data on the systems that various laboratories were pursuing currently. It was recognized that minimum standards for equipment and instrumentation should be established for underwater television surveys. However, these standards will need to be evaluated on a case-by-case basis given the heterogeneity of the grounds and methods being used in survey. For example the standards that might apply to a high density ground (>1.0/m2) might not be appropriate for a ground with low densities (<0.1/m2). At a minimum the camera and lighting systems need to be good enough to easily identify burrows (*Nephrops* and non-*Nephrops*) on the seabed. The field of view should be established to minimize the impact of errors associated with edge effects (see section 6.5). If possible the sledge should be instrumented with sensors to calibrate the field of view correctly (see section 6. 1) and monitor distance over ground accurately (section 6.2). It is recognized that increasing the complexity of instruments does come at additional cost and may not be possible with all systems currently in used. The WK recommends that countries evaluated their cameras and instrument systems to ensure they “are fit for purpose”.

3.4 New technologies

Better use of existing technologies

There are many technologies that are potentially useful to improve the current UWTV surveys. The main areas discussed at the meeting included using higher specification cameras (higher resolution, low blurring) multiple cameras, image enhancement (e.g. Lyyn T-38 real time video enhancer), different lighting solutions (halogen, HID, LED, infrared) and greater instrumentation of the sledge. The workshop noted the existence of Study Group on Fisheries Optical Technologies and recommend that a dialogue be established with this SGFOT on the various optical technologies available. The main conclusion was that sensors like turbidity sensors and field of view sensors (height, roll and pitch) would be very important to have on a sledge. These would allow improved estimation of surveyed area and provide and objective basis on which runs could be classified. Cameras with calibration lasers for measuring burrows and *Nephrops* size would also have a direct relevance. In addition, photo-sensors, grabs and CTDs would be advantageous to have on a sledge allowing the efficient collection of ancillary environmental variables. Sledge distance moved remains one problem for area estimates and one improvement on the odometer used by some groups would be Doppler velocity log (DVL) that can be highly accurate for position, distance and direction moved. Fibre optic cable systems allow a considerable increase in transmission bandwidth while decreasing the diameter of the cable. Such bandwidth allows for almost unlimited sensor data to be transmitted (multiple cameras and other sensor data). However the termination of such systems is not always possible undertake at sea (damage repair) and the cost and complexity of the system is high (e.g. cost of optical slip-rings in the winch).

Some advances have been made with sonar technologies for high-resolution ground penetrating systems enabling visualization of areas of sediments with tens of centimetres penetration. This may allow the visualization of *Nephrops* burrow systems and potentially the system could be sledge mounted. However, such systems are still at the edge of development and application.

In section 6.3 and 6.4 the problems of occupancy and burrow identification are discussed. These types of methodological assumptions may require additional technologies such as ROVs, landers or long-term observation sites to tackle fully.

Video image processing technologies (e.g.. IFREMER’s Matisse software) are also improving and techniques like mosaicing footage to generate 2-D maps of burrow distributions on the seabed may be useful to integrate into future UWTV surveys.

Future Technologies

The main new technologies of potential use are Autonomous Underwater Vehicle (AUV) systems that might be deployed to rove around the seabed carrying out UWTV surveys independent of a vessel. Vehicles carry out surveys navigating over pre-planned tracks at fixed height above the bottom carrying such sensors as video, still photography CTD and sonars. This would have several advantages but may involve substantial investment costs (starting at 250 KEuro) depending on vehicle type (depth/duration).

Data management is likely to be a problem for the future given the large volumes of video footage and ancillary data being collected and the future DCR requirement to make the data available to third parties. For most laboratories historical footage is archived and but accessible with some effort. However, new technologies are constantly evolving e.g. web-GIS and ARC-marine GIS platform which might make accessibility of historical data and footage easier.

Table 3.1.1 Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	UK-FRS	UK-CEFAS	IR-MI
	Depth rating		
Sledge	1200 m	300m	<200m
Trawl mount			
Primary Video Camera			
Make	Kongsberg Simrad OE1466, Zoom	Kongsberg-Simrad OE1364/65	Kongsberg-Simrad OE14-366 PAL
Sensor specs	1/4" CCD	OCD	quarter" interline transfer CCD with colour mosaic filter
Effective pixel			
Horizontal resolution	460 lines	460 lines PAL	460 lines PAL
Minimum Illumination	1.7 lux	0.1 lux	1.7 lux
Synchronising system			
Scanning system		625 line/50Hz	625 Line /50Hz CCIR
Video output			1.0V Pk - Pk composite video into 75 Ohms
Signal/Noise ratio			>48dB weighted (AGC off)
Back light compensation			
Gamma correction			
White balance			
Gain control			
Smear effect			
Lens	4.1 - 73.8 mm f1.4 to f3	6.0 mm, f1.4	4.1 - 73.8 mm f1.4 to f3
Focus control	10 mm to infinity	70 mm to infinity	70mm to infinity (wide angle) 820mm to infinity (narrow angle)
Shutter speed			
Secondary/Rear Video Camera			
Make	Kongsberg Simrad OE1358		
Sensor specs	1/2" CCD		
Horizontal resolution	570 lines		
Minimum Illumination	1x10-3 lux		
Focus control	fixed		
Lens	3.7 mm, f1.6		
Iris control	automatic		
Still Camera			
Camera	35 mm benthos stils (1)		Kongsberg-Simrad OE14-108
Resolution			2048*1536 pixels
Digital file format			JPEG
Flash lighting	sync flash		Kongsberg-Simrad OE11-142
Photo control			Software interface
Image recording			Video 625/50Hz PAL
Surface feed (y/n)			y
Type of deployment			Sledge
Image area estimation			None
Memory card capacity			256k
Camera bateries			None
Lighting			
Make			2x Kongsberg-Simrad OE11-135, Halogen bulb
Typical light power (watts)	300W via transformer		
Type of light	Quartz halogen floddlight	LED	
Dynamic light control		Individually controlled on an RS485 serial data bus connected through the tow cable to a PC in the control room	Yes by KONGSBERG SIMRAD OE 1232 Power and Control Unit.
Video recording unit			
Recorder	DVD	Panasonic DMR E95H DVD, Sony GDV200E DVT	Sony DVD RDR recorder/player unit
Interfaces		Kongsberg Seahawk surface control unit and Canford Video Distribution Amplifier	OE1232 Control Units
Capacity	160Gb HDD, 4.7Gb disk (1hr high res recording)	160Gb hard drive, 4.7Gb disk (1 hour high spec)	4.7Gb/disk-1 hour at high res

Table 3.1.1 continued. Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	UK-FRS Depth rating	UK-CEFAS	IR-MI
Battery pack			
Voltage/Amps			
Autonomy			
Charge time			
Interchangebility			
Type	4 x lead acid		
Cable lining			
Type		Steel double armoured	NC-13 (1 coax +6 other cores)
Core construction	Double linned, polypropylene kevlar lined)	single coax	polypropylene
Supplier homepage			
Camera	www.hydrohouse.co.uk		http://www.kongsbergmaritime.com/web/site/Products/UnderwaterImaging/ColourCameras/Colour_Cameras.asp
Lighting			http://www.kongsbergmaritime.com/web/site/Products/UnderwaterImaging/LampsFlashguns/Lamps_Flashguns.asp
Video recorder			http://www.sony.ie/view/ShowProductCategory.action?site=odw_en_IE&category=DVD+Recorder
Video player			
Cable		www.rochestercables.com	http://www.kongsbergmaritime.com/web/site/Products/UnderwaterImaging/Cables/NC_13.asp
Additional equipment fitted			
Altimeter	Remontec - 250kHz, Range 0.5m to 30m, 2000m depth rating, 1cm resolution, RS232 interface		
USBL		HIPAP 500 USBL	IXSEA GAPS USBL
GPS	Garmin 75		
Dredge / grab	Van Veen mini grab (www.eijkelkamp.com)		
Odometer	FRS wheel with t-count and Remontec transmitter	See FRS	
Laser saclers		In house. Four boresight parallel red lasers (Flexpoint FP4 class 3b)3.5 milliWatt type 3b) provide seabed scaling to assist in field of view calibration.	
Video overlay		The video signal is overlaid with information derived from Manual input (Station name etc.) and realtime Position and UTC time decoded from DGPS NMEA signals from the Tower Hydrographic system. The system is configurable in software for different require	
Overall system:			
Dimensions			1.8m*2.4m*1.5m
Weight			80kgs

Table 3.1.1 continued. Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	UK-UMBS	UK-AFBI	NZ-NIWA
Sledge		<200	
Trawl mount			
Primary Video Camera			
Make	Kongsberg-Simrad colour (OE 1362 and OE 1360) and B&W with infrared capability (OE 1366)	Kongsberg Simrad (Aberdeen, UK) U/W colour video camera.	
Sensor specs			
Effective pixel			
Horizontal resolution			
Minimum Illumination			
Synchronising system			
Scanning system			
Video output			
Signal/Noise ratio			
Back light compensation			
Gamma correction			
White balance			
Gain control			
Smear effect			
Lens			
Focus control			
Shutter speed			
Secondary/Rear Video Camera			
Make			
Sensor specs			
Horizontal resolution			
Minimum Illumination			
Focus control			
Lens			
Iris control			
Still Camera			
Camera			Nikon Coolpix 5000 / 5 Mp. Firmware v1.8
Resolution			2560 x 1920
Digital file format			RAW
Flash lighting			Nikon SB-80DX or SB-800 speedlight
Photo control			Purpose built programmable micro controlled with ATMEL AT902313 2K flash 10MHz microprocessor
Image recording			Compact flash card
Surface feed (y/n)			n
Type of deployment			
Image area estimation			
Memory card capacity			1Gb
Camera bateries			
Lighting			
Make	Versabeam 500W or 2x 300W Kongsberg-Simrad flodlights	Potosea (California) 1500S strobe.	
Typical light power (watts)			
Type of light			
Dynamic light control			
Video recording unit			
Recorder		Standard DVD recorder (replacing Pansonic SuperVHS video recorder.	
Interfaces			
Capacity			

Table 3.1.1 continued. Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	UK-UMBS	UK-AFBI	NZ-NIWA
Battery pack			
Voltage/Amps			
Autonomy			
Charge time			
Interchangebility			
Type			4 x 7.2V Ni-Cad rechargeable high capacity wide temperature range Sanyo KR-5000DEL
Cable lining			
Type			
Core construction			
Supplier homepage			
Camera			
Lighting			
Video recorder			
Video player			
Cable			
Additional equipment fitted			
Altimeter			Furuno CN22 net sounder
USBL			
GPS		yes	
Dredge / grab			
Odometer	FRS Model		
Laser saclers			y
Video overlay			
Overall system:			
Dimensions			1620 x 630 x 1190 mm
Weight			190 kg (300 kg w/ floodlights and batteries)

Table 3.1.1 continued. Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	DK-DIFRES	D-IFM	GR-HCMR
Sledge	150m	500m	1000m/600m
Trawl mount			
Primary Video Camera			
Make	ROS, Inspector,		
	monochrome		Tritech ISS/VNS
Sensor specs		SIT,TVP,CCD, own	
	1/4" Exview HAD CCD	constructions bw/color	1/4 in CCD
Effective pixel			795x596
Horizontal resolution			470 lins PAL
Minimum Illumination	470 lins PAL	SIT 5x10 -5 lux	0.1-0.2 lux
Synchronising system	0.7lux		
Scanning system			2:1 Interface PAL CCIR 50
	635 lines/ 50 Hz CCIR		Hz
Video output			
	analog	analogue	Analogue
Signal/Noise ratio			
	>50db		
Back light compensation			
Gamma correction			
White balance			
			Auto
Gain control			Auto
Smear effect			
Lens			f1.6, 4-88 m zoom 47-2.2
	3.8mm f/0.8		deg. Angle
Focus control	152mm to infinity	fixed and adjustable	yes
Shutter speed			
Secondary/Rear Video Camera			
Make	ROS, INSPECTOR		
Sensor specs			
	1/2" interline transfer CCD		
Horizontal resolution	570 lines		
Minimum Illumination	3.4x10-4 lux		
Focus control	3.8mm f/0.8		
Lens			
Iris control	152mm to infinity		
Still Camera	automatic		
Camera		TVP, Camel	
Resolution	NA		
Digital file format	NA		
Flash lighting	NA		
Photo control	NA		
Image recording	NA		
Surface feed (y/n)	NA		
Type of deployment	NA		
Image area estimation	NA		
Memory card capacity	NA		
Camera bateries	NA		
	NA		
Lighting			
Make	ROS, QL-3000		
Typical light power (watts)			Quartz: 2x250 W, HID:
	250W	150/300	2x75W
Type of light	Halogen	halogen	HID, quartz
Dynamic light control	YES by a ROS IC-15		
	Controller	no	quartz only
Video recording unit			
Recorder			
	Phillips DVD recorder	Sony S-VHS, DV, U-matic	DVD, VHS
Interfaces			
	ROS control box IC-15		Digital, analogue
Capacity			120 Gb (60hrs), 3hr video
	250GB		cassettes

Table 3.1.1 continued. Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	DK-DIFRES	D-IFM	GR-HCMR
Battery pack			
Voltage/Amps			
Autonomy			
Charge time			
Interchangebility			
Type			
Cable lining			
Type	MacArtney, type 6926	500m Kevlar cable 16 slip rings	
Core construction	1 coax, 8 -1mm, 5twisted, 4twisted, polypropylene jacket with a kvelar brain		
Supplier homepage			
Camera	http://rosys.com/	Ospery	Tritech
Lighting	http://rosys.com/	Ospery	DSPL
Video recorder	http://www.philips.com/	Sony S-VHS, DV	Sony, Panasonic
Video player	SANOY		
Cable	NA		Coortland-fibron
	NA		
Additional equipment fitted			
Altimeter	NA		
USBL	NA		
GPS	from the vessel		
Dredge / grab	NA		
Odometer	NA		
Laser saclers	NA		
Video overlay	NA		
Overall system:			
Dimensions			
Weight			

Table 3.1.1 continued. Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	PT-IPIMAR
Sledge	
Trawl mount	2000
Primary Video Camera	
Make	Tritech
Sensor specs	1/3'' DSP Sony Colour CCD
Effective pixel	PAL 752 (H) x 582 (V)
Horizontal resolution	480 lines
Minimum Illumination	0.1 lux @ f2.0
Synchronising system	Internal
Scanning system	PAL 625 lines
Video output	1.00 V peak to peak composite 75 Ω
Signal/Noise ratio	More than 50 dB (AutoGain control off)
Back light compensation	Automatic
Gamma correction	0.46
White balance	2100ºK – 8200ºK AutoControl
Gain control	4dB – 30 dB AutoControl
Smear effect	0.01%
Lens	
Focus control	Preset (+/- 12V to 24V)
Shutter speed	PAL 1/50 to 1/100 secs
Secondary/Rear Video Camera	
Make	
Sensor specs	
Horizontal resolution	
Minimum Illumination	
Focus control	
Lens	
Iris control	
Still Camera	
Camera	
Resolution	
Digital file format	
Flash lighting	
Photo control	
Image recording	
Surface feed (y/n)	
Type of deployment	
Image area estimation	
Memory card capacity	
Camera bateries	
Lighting	
Make	
Typical light power (watts)	>120 lumens
Type of light	LED
Dynamic light control	automatic
Video recording unit	
Recorder	Archos based engine MPEG-4 optimised for TV up to 640x480 @ 30 fps in AVI format
Interfaces	USB 2.0 high-speed device compatible for USB host port compatible Mass Storage DevicePC and MAC
Capacity	30 Gb HDD storing up to 30 hrs video

Table 3.1.1 continued. Specifications of camera and other sledge instrumentation used for *Nephrops* UWTV surveys by various laboratories.

Type of equipment	PT-IPIMAR
Battery pack	
Voltage/Amps	16.8V / 8.2A
Autonomy	10hrs
Charge time	14hrs
Interchangebility	No
Type	Li-Ion
Cable lining	
Type	
Core construction	
Supplier homepage	
Camera	www.tritech.com
Lighting	www.tritech.com
Video recorder	www.tritech.com
Video player	
Cable	
Additional equipment fitted	
Altimeter	
USBL	
GPS	
Dredge / grab	
Odometer	
Laser saclers	
Video overlay	
Overall system:	
Dimensions	
Weight	

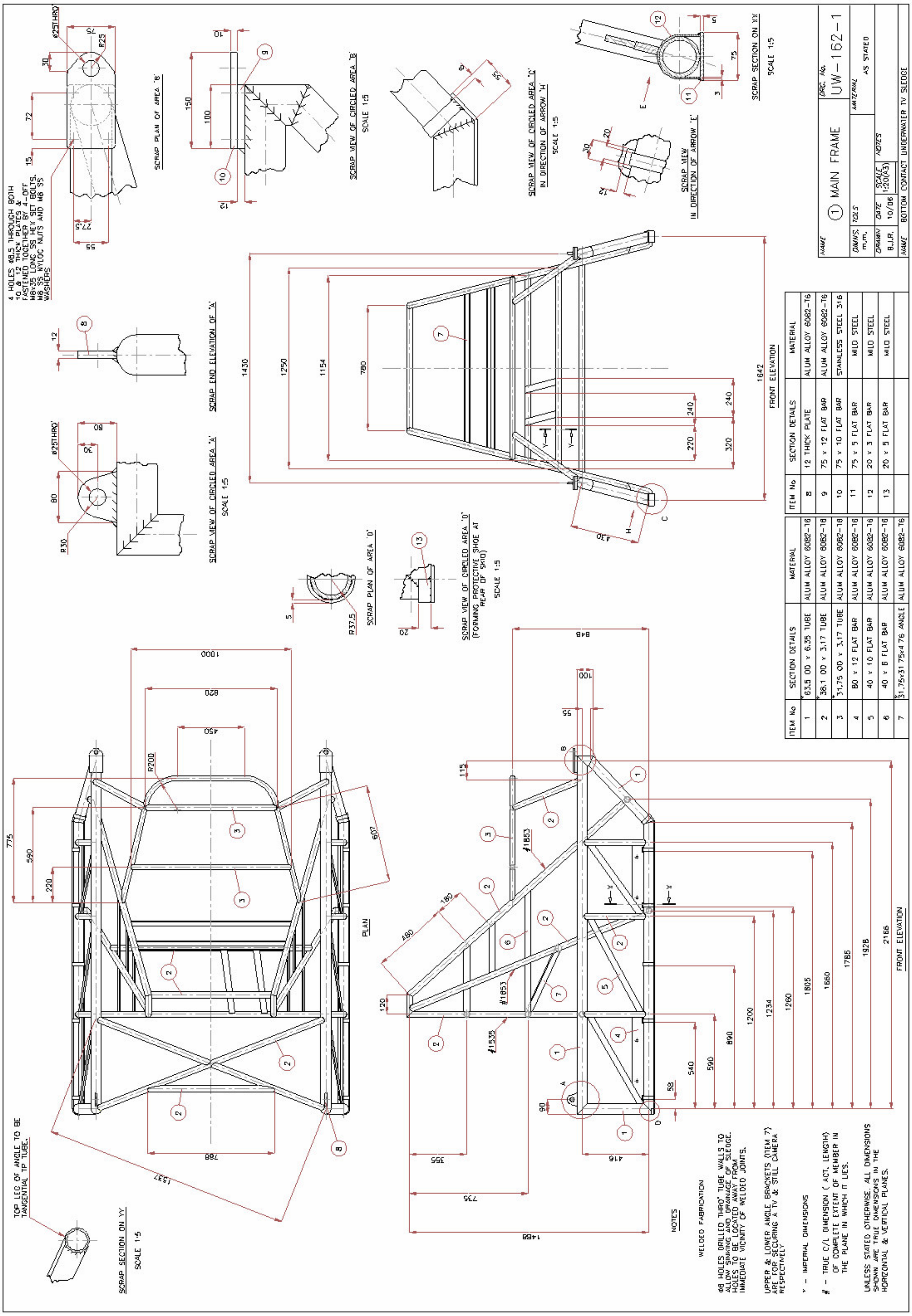

Fig 3.1.1. Design drawings for the towed sledge (UK-FRS).

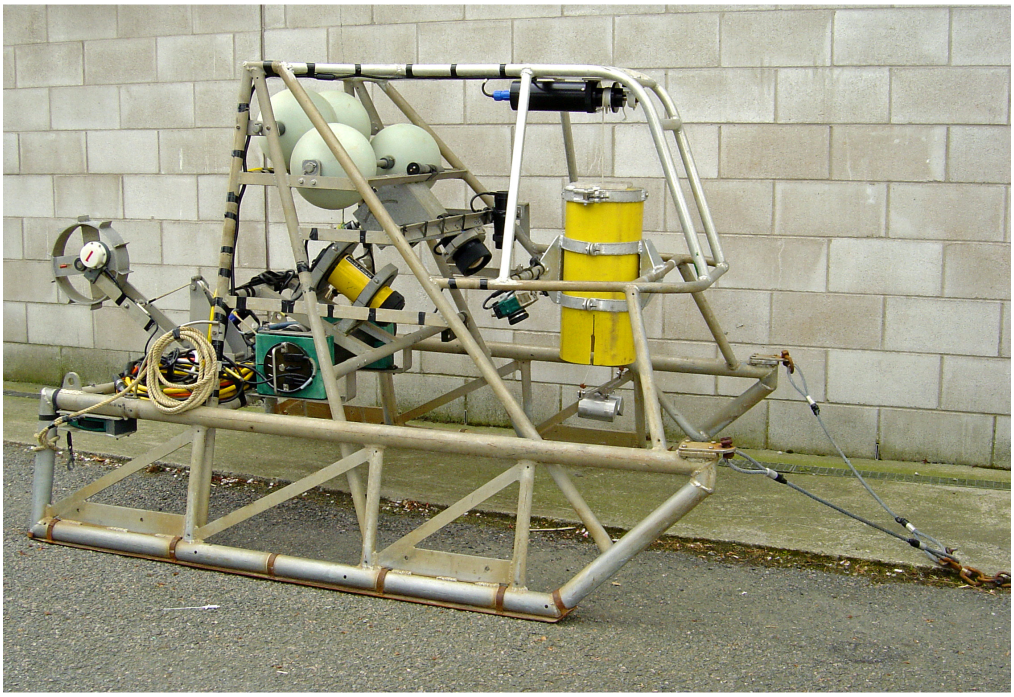

Figure 3.1.2. Picture of the sledge used by FRS for *Nephrops* TV survey (UK-FRS).

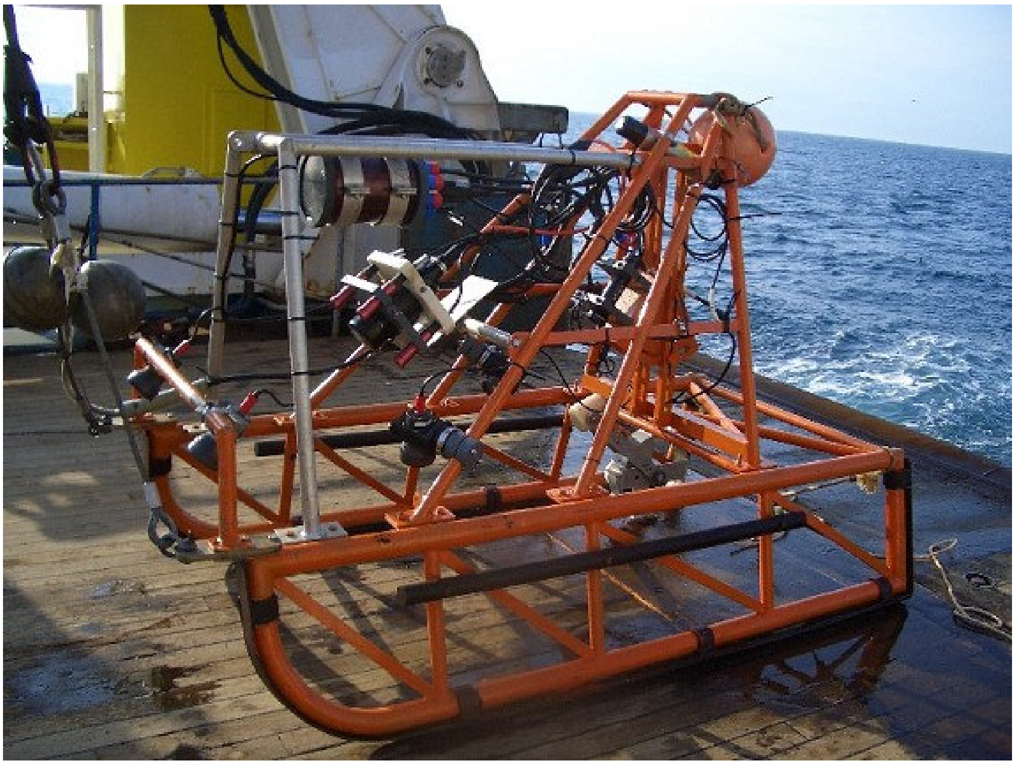

Figure 3.1.3 Picture of the sledge used on the Cefas 2006 *Nephrops* TV survey (UK-CEFAS).

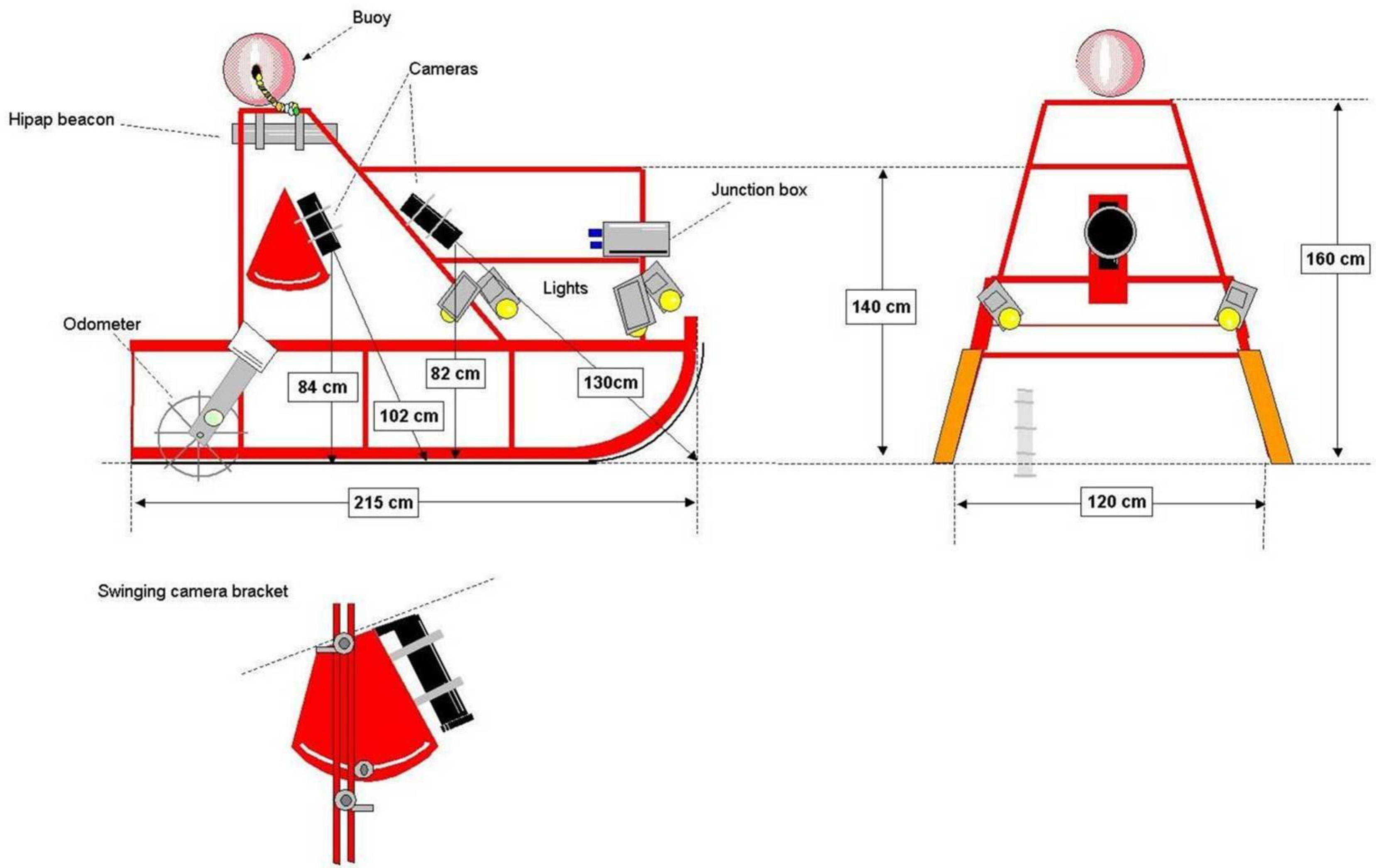

Figure 3.1.4. Diagram of the size and set-up of the Cefas 2006 *Nephrops* TV survey sledge (UK-CEFAS).

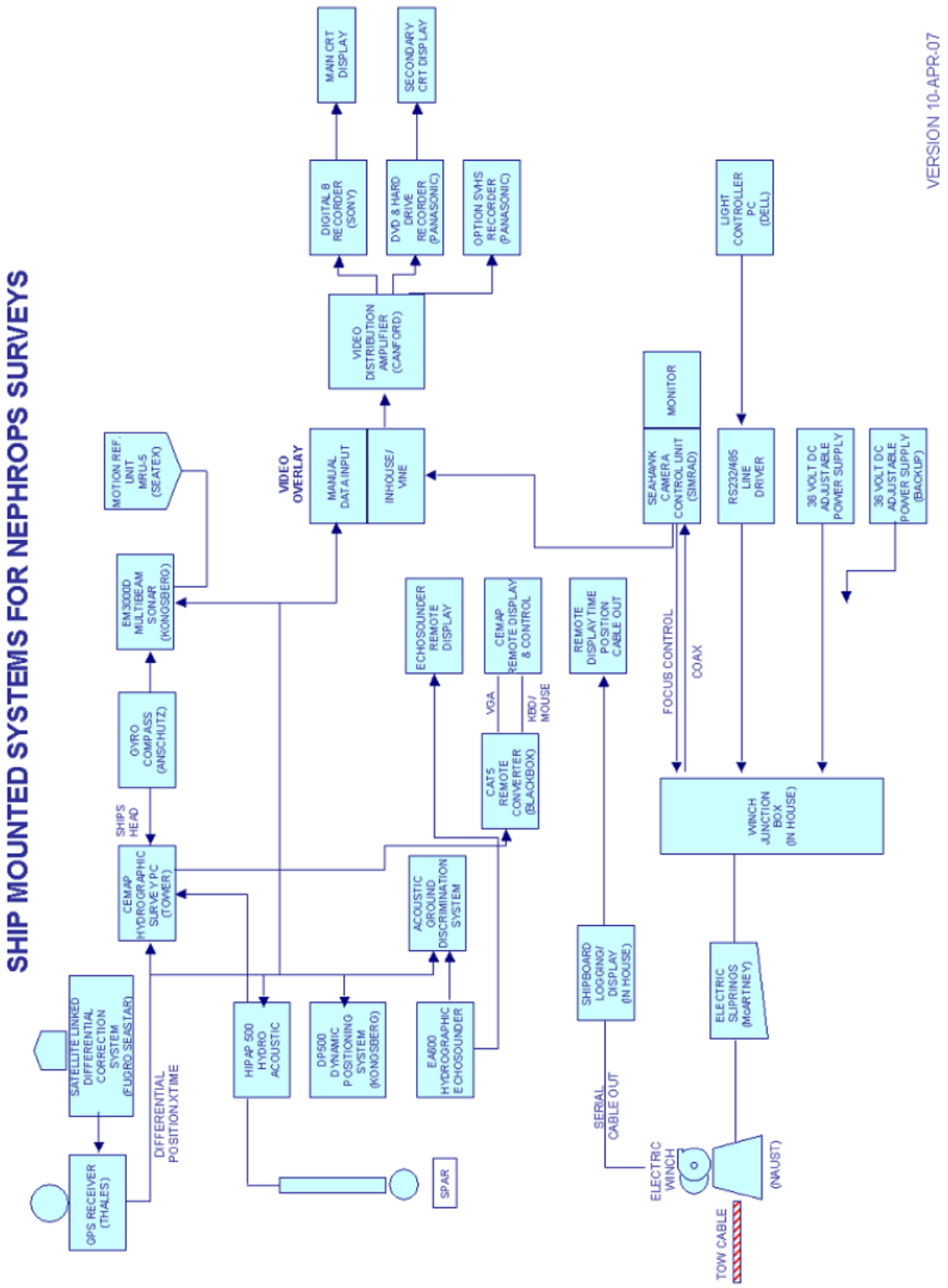

Figure 3.1.5 Schematic of the Cefas sledge and shipboard set-up for the 2006 *Nephrops* TV survey (UK-CEFAS).

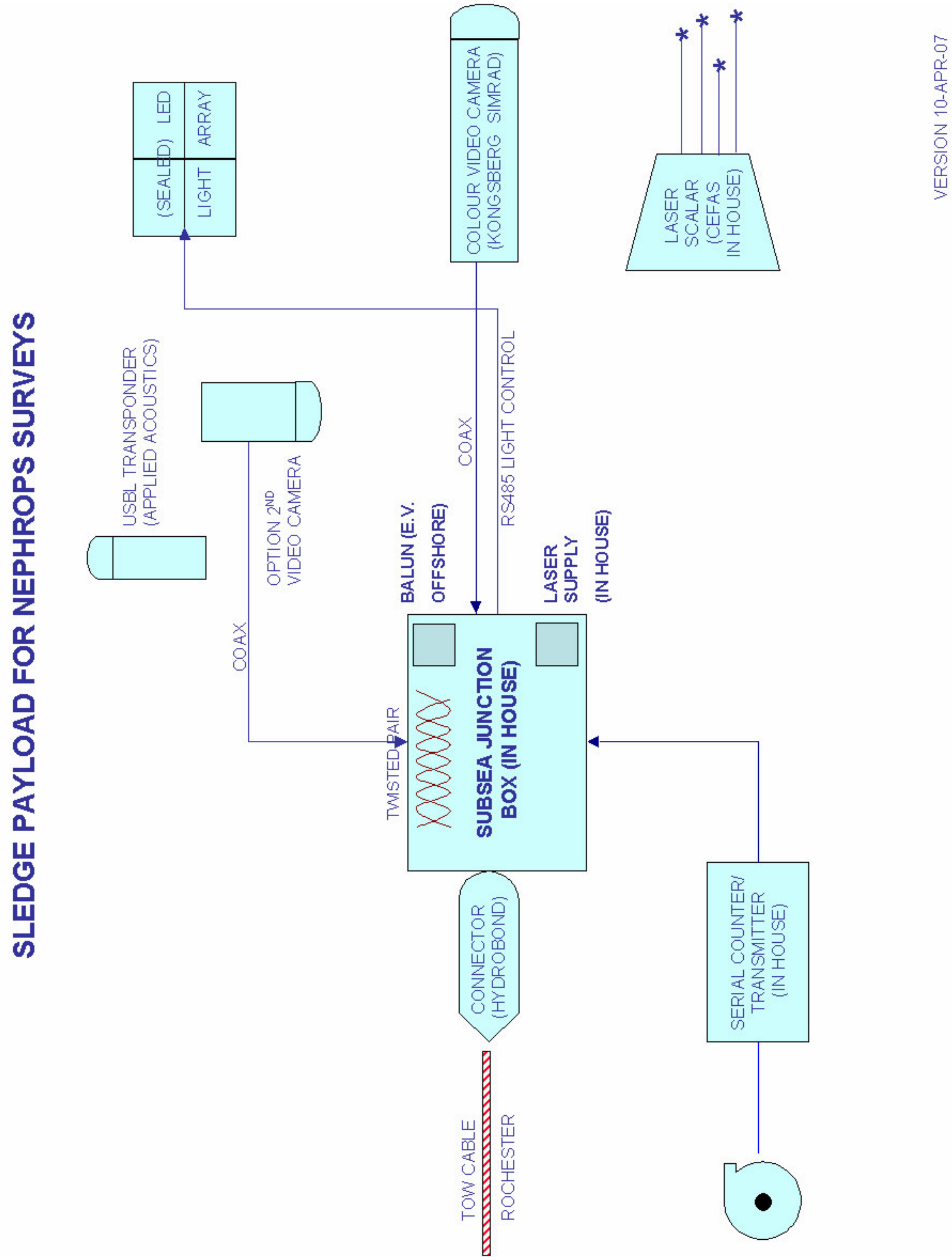

Figure 3.1.6. Schematic of the Cefas sledge and sledge pay-load the 2006 *Nephrops* TV survey (UK-CEFAS).

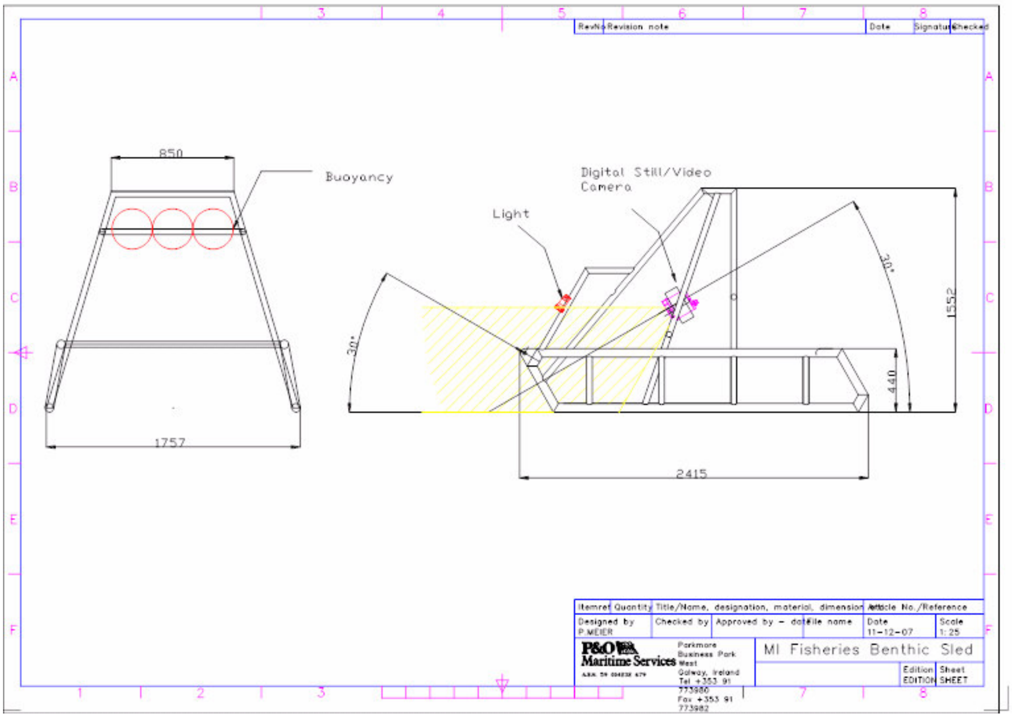

Figure 3.1.7. Marine Institute Ireland UWTV sledge loosely based on Aberdeen design (IR-MI).

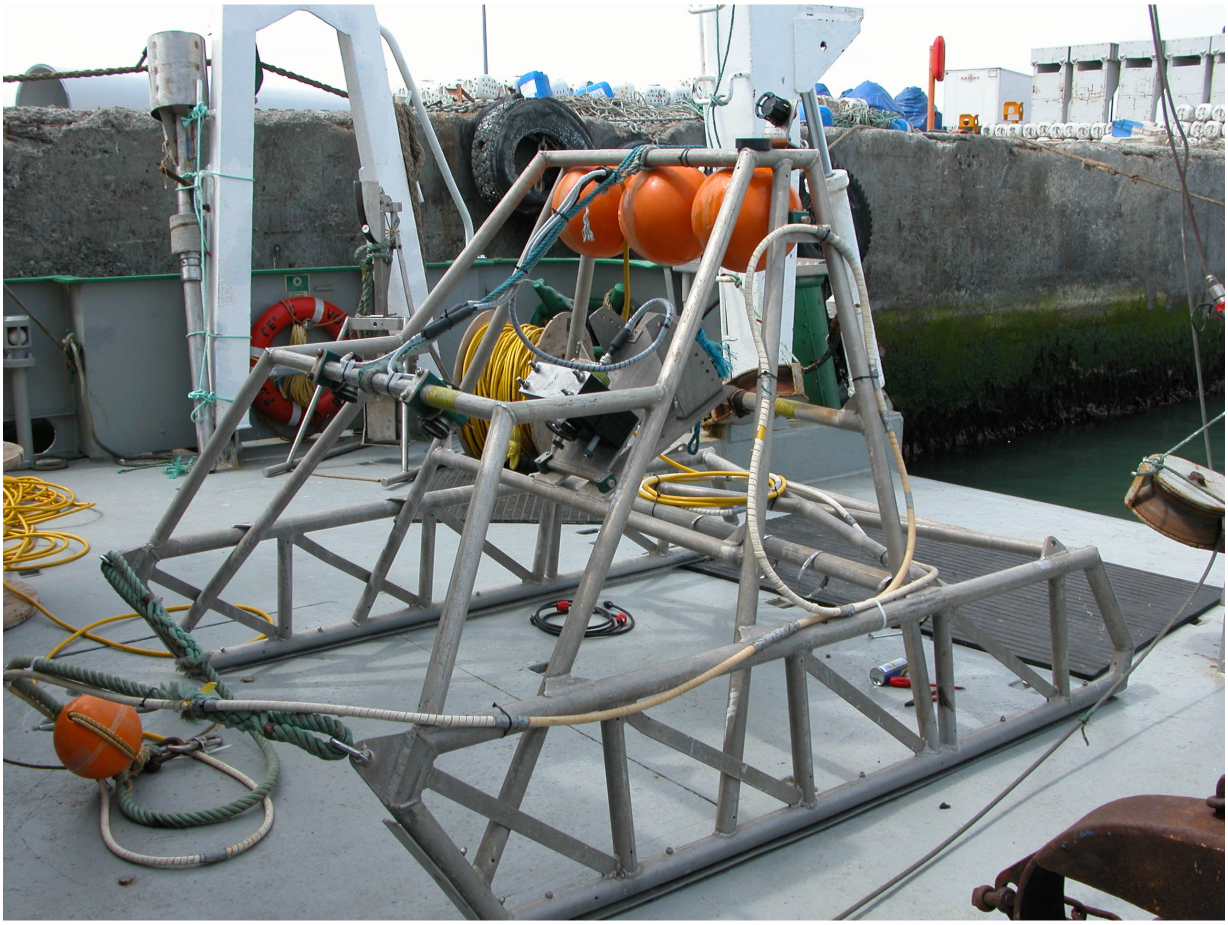

Figure 3.1.8. Photograph of the Marine Institute Ireland UWTV sledge (IR-MI).

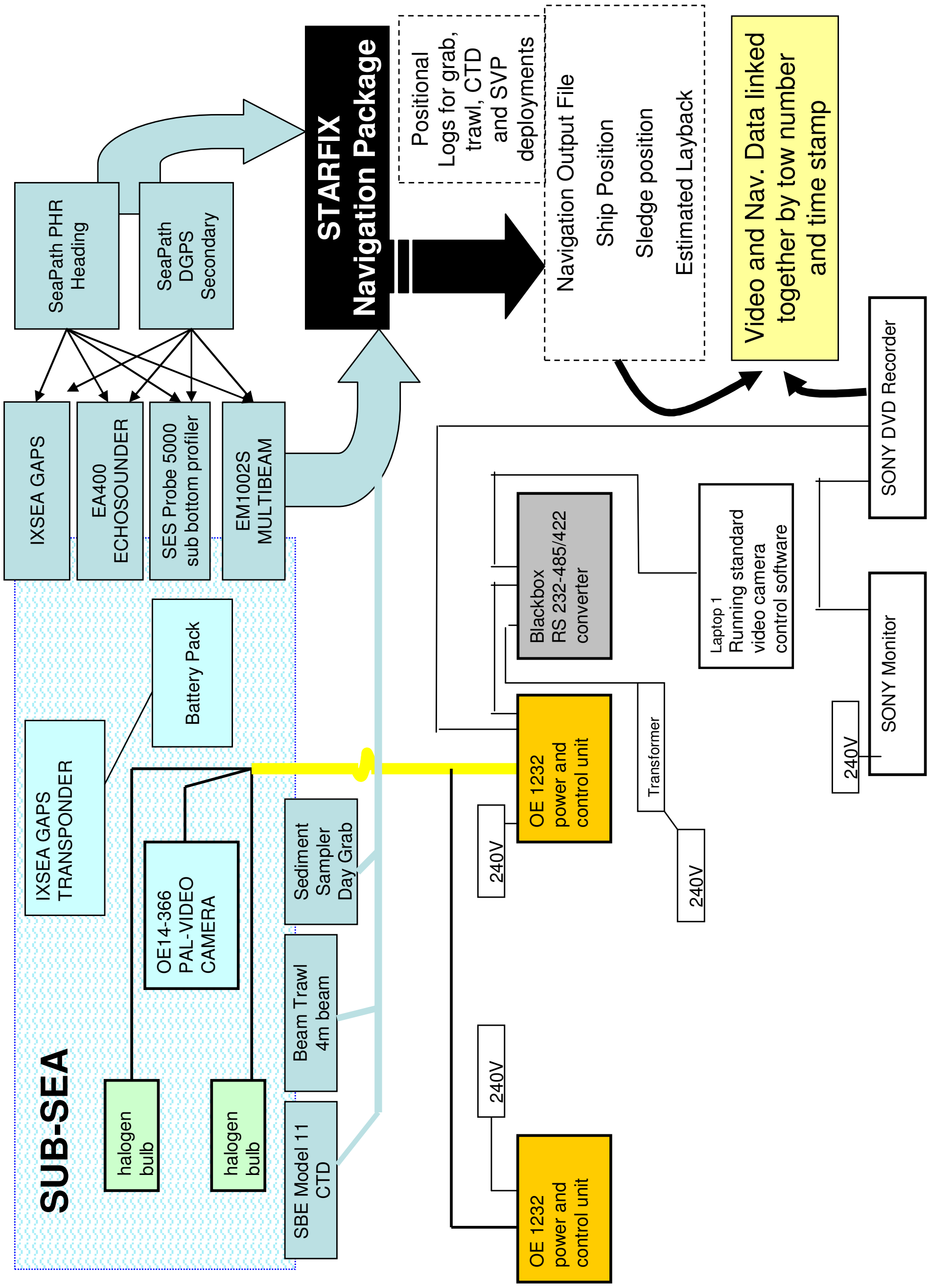

Figure 3.1.9 Marine Institute *Nephrops* underwater TV equipment and data schema 2006 (IR-MI).

4 Survey design

4.1 A review of survey design

4.1.1 Scottish (FRS) UWTV surveys

In Scottish waters, most exploited populations of *Nephrops norvegicus* are found at depths of between 40 and 200 m (Howard, 1982), on fine cohesive muddy sediments suitable for burrow-building (Alfonso-Dias, 1998). The distribution of these sediments around the UK has generally been well defined (BGS, 2002). The feasibility of using underwater TV surveys to estimate *Nephrops* burrow density on muddy sediments was investigated in inshore waters during the 1980s (Bailey and Chapman, 1983; Chapman, 1985, Alfonso-Dias, 1998). In 1992, RV *Scotia* carried out the first combined TV and trawling survey of the Fladen ground (Chapman *et.al.,* 1994).

Since 1992, TV surveys have been carried out on a regular basis by FRS at a number of sites around Scotland. Additionally, a number of sites outside these areas have been surveyed for purposes not directly related to the assessment process, such as Loch Torridon, the Buzzard oil-field, Devil's Hole or deep waters around Rockall. Since June 2004, TV surveys have been carried out under the EU DCR.

Because of the number of areas which are surveyed by FRS, the varying nature of the fishery and variable sediment distributions within each, the development of the TV survey has been something of an evolutionary process, and slightly different methods of survey design are applied in each area. These are summarized in Working Document 4.

The underlying approach of the FRS TV survey is to adopt a random stratified survey design, and where necessary, subject this randomness to certain fixed geographical limits to ensure adequate coverage of the whole fished area, preventing the localized depletion of units within the fishery from going unnoticed. Generally, the strata are based on Folk sediment types M (mud) sM (sandy mud) and mS (muddy sand) (Folk, 1954). Sediment samples have been collected at each sledge deployment since 1992, with the aim of testing the appropriateness of our strata boundaries, and where possible to produce improved maps of sediment distribution.

Functional Unit 7 (Fladen)

The Fladen (Functional Unit 7) is situated in Management Unit G, off the northeast coast of Scotland from the Moray Firth to the Shetland Islands, and as far east as the 2°E meridian. There are other *Nephrops* populations in management unit G, on muddy sediments to the northwest of the Shetland Islands, over the shelf edge.

The Fladen is one of the most carefully surveyed areas of sediment off the UK coast, thanks to the oil and gas industry. It is the largest area of *Nephrops*-type sediment in Scottish waters, covering approximately 30 000 km^2 of suitable sediment, of which 20 004 km^2 are muddy sand, 9492 km^2 are sandy mud and 1137 km^2 are mud.

Afonso-Dias (1998) showed that variance in abundance estimates could be minimized by using percentage silt and clay in the sediment, rather than Folk sediment type, as the basis for stratification. Muddy sand and sandy mud cover a wide range of sediment compositions (10–80% silt and clay), and more precise results were obtained by using strata of 10%, 45%, 55% and 80% silt and clay in sediment.

Samples are distributed randomly within strata, with the proviso that a certain number of samples must be carried out in each of the four quarters of the Fladen. 8 fixed stations are also visited on each survey.

The Fladen has been surveyed annually since 1998, with around 50–70 stations per year. Although this is the highest number of stations carried out in a functional unit by FRS, because of the large area of the Fladen, the density of stations is rather low.

Functional Unit 8 (Firth of Forth)

The Firth of Forth functional unit (FU 8) is located on the southeast coast of Scotland, and covers ICES rectangles 40E7 and 41E6–7. It is bounded to the east by the 2ºW meridian, and to the north by the 56 º30’N circle of latitude. To the west and south the functional unit is bounded by the Fife and Lothian coastlines. The Firth of Forth shares a border with the Farn Deeps functional unit (FU6) in 40E7.

Within the functional unit, a contiguous body of suitable sediment (973 km^2), mainly muddy sand (782 km^2) with significant areas of sandy mud (189 km^2) and a very small area of mud (2 km^2), extends from the western limit of BGS sampling, around the Forth Road Bridge, to the near English border, off the coast of Eyemouth. Around 25 km north of the Forth *Nephrops* grounds, off the coast of Arbroath, another patch of suitable sediment is found, consisting of muddy sand with small patches of sandy mud. This patch covers an area of approximately 250 km^2. The Farn Deeps grounds are approximately 70 km to the southeast of the eastern-most end of the Forth grounds.

The Firth of Forth has been sampled on a regular basis since the instigation of the Scottish TV survey. Sampling has been carried out on RV *Clupea*, mainly in July. Sampling is carried out on a random stratified basis, with samples being randomly distributed in the three sediment strata, subject to the provision that a certain number of samples are located in eastern, central and western portions of the suitable sediment area, defined by the 2°48’ and 2°32’W meridians. The area of sediment off Arbroath has not been sampled on a regular basis.

Functional Unit 9 (Moray Firth)

The Moray Firth is located off the northeast coast of Scotland, and consists of ICES rectangles 44E6–8 and 45E6–7. Sediments in the Moray Firth and Noup have been surveyed by BGS, and show a good level of sampling, with the only unsampled area being at the far western end of the Moray Firth, near the Kessock channel and Beauly Firth. The Moray Firth consists of 2032 km^2 of muddy sand, 191 km^2 of sandy mud, and 12 km^2 of mud. These are distributed in single patches in each functional unit. The muddy sediments in the Moray Firth encircle patches of sandy sediments within the muddy area.

The Moray Firth has been sampled on an annual basis, with between 30 and 55 stations sampled per year since 1998 (technical difficulties meant that only 13 stations were sampled in 2006). To ensure adequate spatial coverage, the Moray Firth is divided into three sections – western, central and eastern. Stratification is then by Folk sediment type, with samples randomly distributed within each sediment type.

Functional Unit 10 (Noup)

The Noup is located to the northwest of the Orkney Islands and consists of ICES rectangle 47E6. It comprises a single patch of 409 km^2 of muddy sand. As a patch of a single sediment type, the Noup is sampled randomly. Around 10 stations per survey have been investigated. Sampling effort at the Noup has been sporadic, with surveys taking place in 1994, 1999, 2005 and 2006.

Functional Unit 11 (North Minch)

The North Minch Functional Unit (FU 11) is located off the northwest coast of Scotland. The northern boundary of the FU is the 59°N line, although there are no areas of suitable sediment north of 58°30'N. The boundary with the South Minch FU is at 57°30'N. The North Minch includes areas of sediment in the Inner Sound, between Skye and the mainland.

The resolution of BGS sediment survey data is not ideal in this area – coverage of coastal areas and sea-lochs is poor or lacking altogether. The North Minch as a whole contains 1775 km^2 of suitable sediments. These consist of 669 km^2 of muddy sand, 519 km^2 sandy mud and 534 km^2 of mud. A single patch occupies the area between Skye and the mainland, with one "leg" stretching down into the Inner Sound, and the other into the Sound of Raasay. This patch is separated by sandy sediments from a second area, stretching between Lewis and the mainland. This area consists of mud, muddy sand and sandy mud, as well as the slightly gravelly variants of these sediments. Uncertainty exists as to the suitability of these slightly gravelly areas for *Nephrops*; however, anecdotal evidence from the fishing industry suggests that they consider the whole of this area as suitable *Nephrops* ground.

Because of this uncertainty in sediment distribution and suitability, the North Minch is divided into four arbitrary rectangles, roughly corresponding to discrete patches of mud in (or on the border of) the functional unit, for survey purposes. Samples are distributed randomly over the area of suitable sediment within each rectangle. In the assessment, burrow densities in the four rectangles are raised to the area of suitable sediment in each region.

Sampling effort is distributed such that 14–15 stations are surveyed in rectangle U, 9–10 in rectangle V, 10–11 in rectangle W and 4–6 in rectangle X. There are also 12 fixed stations in the North Minch which are visited every year. For assessment purposes, estimates of burrow density in each rectangle are raised to the area of mud, sandy mud and muddy sand in that rectangle and summed to obtain an estimate of the population size in the whole North Minch.

Functional Unit 12 (South Minch)

The South Minch functional unit (FU12) is located off the west coast of Scotland, and is bounded to the north and south by the 56°00' and 57°30' circles of latitude, and to the west by the 8°W meridian. Out with the functional unit, a mixed fishery for gadoids and *Nephrops* takes place on Stanton Bank, to the southwest of the Outer Hebrides.

BGS survey data shows the South Minch to contain a number of patches of suitable sediments, totalling an area of 5023 km^2. This comprises 2720 km^2 of muddy sand, 2059 km^2 of sandy mud and 244 km^2 of mud. Suitable sediments to the east of Skye are included in the North Minch Functional Unit. A single patch of muddy sediments extends southwards from the southwest coast of Skye to the Ardnamurchan peninsula and westwards to a point around 30 km southwest of Barra. A further patch of muddy sand and sandy mud is found to the west of Mull. Other patches are found in a number of sea-lochs. BGS sampling in this area is far from comprehensive, and estimates of sediment area should be taken as minima. A number of small patches of muddy sand and sandy mud are found at Stanton Bank. A further area of muddy sand approximately 80 km to the west of North Uist, although still on the shelf edge, is currently lightly fished.

The South Minch is sampled randomly, based on three strata, based on Folk sediment type, with a fixed ratio of samples carried out in each of three geographic areas (west, southern and east) and an additional four fixed stations. Sampling at Stanton Bank is carried out at six fixed positions. The sediment to the west of Uist has not been sampled as part of the regular TV survey, but occasional samples have been taken from this area on the deepwater survey. An uninterrupted series of data is available from 1998, with approximately 35–50 stations being examined in each year.

Functional Unit 13 (Clyde)

Functional unit 13, found on the southwest coast of Scotland, contains two recognized areas of *Nephrops* ground, separated by the Kintyre peninsula. To the east, the major area of sediment in the Firth of Clyde, and to the west the smaller Sound of Jura. The functional unit is bounded to the west by the 6°W meridian, to the south and north by the 55°N and 56°N circle of latitude.

According to the BGS sediment data, functional unit 13 contains 2097 km^2 of muddy sediments (Figure 4). This is divided into muddy sand (668 km^2), sandy mud (708 km^2) and mud (719 km^2). In the Firth of Clyde these sediments occupy the main body of the Firth, to the east and west of the island of Arran, and extending northward, into the Kyle of Bute, Loch Fyne and the Upper Firth of Clyde. Towards the southwest end of the Firth, sediments become progressively sandier, with some sandy gravel and gravels. A small area of slightly gravelly mud is found just outside the functional unit, in the southern end of Loch Ryan, between Cairnryan and Stranraer. This area is the site of an oyster fishery, and not considered suitable for *Nephrops* due to its shallow depth. The Clyde sediments are separated by around 40 km of sand and gravel sediments from the nearest areas of mud in the northern Irish Sea.

The Sound of Jura contains a single patch of muddy sediment, bounded to the north by bare rock. This area is relatively close, as the crow flies, to the South Minch functional unit; however poor sediment sampling resolution in this area means this is difficult to quantify.

For survey purposes, the Clyde is a random stratified survey, based on the area of the three Folk sediment classification mud types, divided into northern and southern regions along the 56°30' line, with an additional six fixed position stations. Sampling in the Sound of Jura is stratified into three areas by Folk sediment type without any geographical limitations.

An uninterrupted series of annual underwater TV surveys are available since 1999 for the Firth of Clyde. The numbers of valid stations in the survey have remained relatively stable throughout the time period, in the order of 35–45. The TV survey for the Sound of Jura was not conducted between 1997 and 2000, and also 2004.

Other Areas

FRS conducts *Nephrops* TV surveys at a number of sites which are not directly related to the assessment process. These include habitat monitoring, establishing baseline burrow densities in undeveloped and developing *Nephrops* fisheries and surveys in support of policy. TV surveys have been carried out at:

- Devil's Hole
- Rockall / shelf edge
- West coast sea lochs
- the Buzzard oil field

4.1.1.1 Conclusions

The FRS *Nephrops* TV surveys covers a substantial proportion of the sediments suitable for *Nephrops* burrows in waters around Scotland. The growth of the survey over the period 1992–2007 is evident from a comparison of the different techniques applied to each functional unit. The survey process could benefit from some rationalisation, such as an analysis of the appropriate level of effort to apply to each FU, and a consistent approach to stratification across FUs. The survey could be extended to cover areas such as the Devil's Hole or Arbroath; however, these are not currently included separately in assessments, and as such are of lower priority.

4.1.2 English (Cefas) UWTV surveys

The Farn Deeps TV survey is based on an initial random stratified design. The survey was designed to cover the extent of the fishery while ensuring spatial coverage. FRS was consulted to determine method and gear. Cefas consulted the industry to confirm estimates of the extent of the fishery and to get clear trawl positions. Based on prior knowledge of the habitat of *Nephrops*, the original survey area was limited to the extent of the mS displayed on British Geological Survey sediment charts. The area was stratified by a grid 10 minutes latitude by 10 minutes longitude. The number of stations per grid ranged from 2 to 4 depending on the area of mS within the box. The aim was to collect a minimum of 10 minutes clear video at each station for reanalysis ashore. Sediment data were also collected with the idea that it would provide a finer scale to re-stratify the area. The first survey was carried out in spring 1996 at the end of the fishing season.

The same stations were fixed for subsequent surveys but further stations were added to better define the edge of the survey area and to increase the coverage of higher burrow density areas.

Subsequent surveys were carried out at the start and end of the season to investigate depletion. Two surveys one at the start and one at the end of the 2001–2002 season were adapted to examine spatial patterns at different spatial scales and to measure variance on replicate tows and to investigate depletion. In addition to the standard stations, 10 clusters of six stations were carried out with each station repeated three times (Bell *et.al.* 2005; Figure 4.1).

By 2003 the Farn deeps survey had evolved into a fixed station survey of 105 stations carried out in autumn at the start of the fishing season (Figure 4.2). Because of the limited survey time the stations are prioritized based on their success in previous surveys with the idea of maintaining consistency between surveys.

Using the Farn Deeps survey design as a model, two surveys were carried out in1997 and 1998 in the Eastern Irish Sea (Figure 4.3). The initial survey area covered a greater range of sediment types to try and identify the limits of the fishery at the outset. However, the success of these surveys was limited because of weather and visibility.

4.1.3 Irish (MI) UWTV surveys

The surveys in the Aran Grounds, Irish Sea and Celtic Sea were designed with the following objectives in mind:

- To give an unbiased estimate of *Nephrops* burrow abundance
- To obtain the best precision for an estimate of the variance of the above.
- To map accurately the spatial distribution of the *Nephrops* grounds
- To obtain addition biological and habitat data.

The number of UWTV stations, survey days and beam and trawl tows over time is given in Table 4.2 and the spatial distribution of stations is given in Figure 4.4. Before the survey series were commenced varying levels of information was available on which design decisions could be based. Irish surveys commenced with and exploratory survey on the Aran Grounds and nearby grounds in 2002. The approach at each UWTV sampling site is described in detail in Section 5 but, in summary, a video transect (generally 10 minutes) and a grab sample (in most cases) are taken.

For the Aran Grounds no prior information was available on the distribution of sediments but the boundaries of the fishing grounds were obtained from the fishing industry and through a previous trawl survey in 2001. The initial design was based on a grid of 3*3 miles with 2 random stations selected within each square. This was chose to obtain the best compromise between statistical need for randomization and the need for good spatial coverage. In 2003 the survey design for the main area the Aran Grounds changes to a randomized fixed grid where a point was picked at random and stations were carried out at a fixed distance north-south and east-west. The distance between stations varied somewhat but is currently 2.25 nautical miles.

An adaptive approach is taken whereby stations are continued past the known perimeter of the ground until the burrow densities are close to zero.

In the Irish Sea information on the distribution of sediment was initially obtained from AFBI habitat sampling programmes and this served as the basis of the initial domain area. The survey commenced in 2003 and a randomized fixed grid design has been used for all the Irish Sea surveys. The spacing between stations is ~3.5 nautical miles. In the Celtic Sea the first survey took place in 2006. The BGS sediment distributions and VMS data for known Irish vessels on *Nephrops*-directed trips was used to look at the spatial distribution of the ground. The main fishing effort for Irish vessels was concentrated in an area known as the "Smalls" which is a deep muddy basin called the Celtic Sea deep. Over this area a randomized fixed grid at 3 nautical mile spacing was used. Several other areas where *Nephrops* fisheries took place were also surveyed.

The geostatistical analysis of survey data to date does not suggest a sill in the variogram which might indicate a suitable distance for survey spacing (Working Document 2, Annex 2). A further examination of the statistical properties of the surveys should be carried out in the near future. The objective will be look at how survey design might be optimized.

In additional to the *Nephrops* burrow densities over recent years the ancillary data collected on the surveys has increased substantially. The WD 2 gives a typical range of data collected on the surveys. Fishing with a 4-m beam trawl has been added to Aran and Celtic Sea surveys to obtain information about sizes of animals in those areas. This is not necessary in the Irish Sea where the UWTV survey is coupled with the extensive AFBI trawl survey. An analysis of UWTV data collected during the survey informs the decision on when and where to conduct fishing operations to maximize catches. The main design objective is to get a reasonably precise length-frequency distribution at each station. In Celtic Sea for example the size range of animals is such that it requires around 350 individuals per station. Tow durations of 30 minutes yielded catches of on average 300 individuals. The optimum number of tows required has yet to be examined but at least 10 stations would be required to bootstrap the distributions in each tow.

The multibeam is generally collected continuously most recently. The randomized nature of the grid means that over time much of the ground could be covered fully by multibeam. If the grid was not randomized a more systematic approach could be used to fill in areas not previously surveyed. In the case of the Aran Grounds it may be more useful to systematically survey the transition zones around the boundary of the grounds in a systematic fashion since data collected thus far points to a homogeneous backscatter in the centre of the ground. Other geotechnical data are collected in an *ad hoc* way in line with UWTV operations and best practice for used by the surveyors. Where CTD operations are carried out during the survey this is based on transects given by oceanographers although there are plans to routinely collect oceanographic data by fitting appropriate instruments to the sledge.

4.1.4 Crete (HMCR) UWTV surveys

Surveys are irregular, and rather than for monitoring, they form part of specific research projects (Smith *et.al.*, 2003, Smith and Papadopoulou, 2003). In the case of single ground investigation 1 or 2 tows might be completed over the area. The tow site is randomly chosen although if a trawl is to be carried out in the area it will be in the line of the proposed trawl. In the case of a particular population area, then fixed stations will be chosen and may be repeated over time. The stations will be chosen to equally cover the area with number of stations dependant on the time available for the survey. The exact tow start point will depend on the day, on the prevailing weather, and on any obstructions (passing trawlers, presence of static bottom gears). Tows will be at least 30 clear minutes on the bottom with counts broken down into 6 x 5-minute sections.

4.1.5 Portuguese (IPIMAR) trawl and camera surveys

Nephrops occurs off the Southwest and South coasts off Portugal in depths greater than 200 meters. These stocks have been covered by trawl surveys since the 1980s, using different research vessels and sampling designs.

In 1997, a stratified sampling design was adopted, based on the design for the demersal fish resources. The sectors and depth strata were the same as those used for the groundfish surveys, from 200 to 750 meters in the southwest coast and from 100 to 750 meters in the south coast. The number of hauls in each stratum was dependent on *Nephrops* and rose shrimp abundance variance, with a minimum of 2 stations per stratum. The average total number of stations in the period 1997–2004 was 60. These surveys were carried out in May-July and had a total duration of 20 days.

Due to the small number of samples in some strata and to the random selection of the positions, this design does not allow the use of geostatistical methods. To address this issue, a regular grid composed by 77 rectangles has been used since 2005 (Figure 4.5), with one station within each rectangle. Each rectangle has dimensions of 6.6 minutes of latitude x 5.5 minutes of longitude for the SW coast and vice versa for the south coast, corresponding approx. to 33 nm^2. The abundance observed at a particular point within the rectangle will reflect the relative abundance of the resource at that geographical area and it is assigned to the centre of the rectangle.

The Portuguese *Nephrops* stocks are deeper than the northern stocks where the UWTV surveys have been carried out. For the Portuguese stocks, a combined trawl and UWTV survey will be carried out in 2007 using an autonomous UWTV recording system attached to the headrope of the trawlnet. Continuous image recording will be carried out along the trawl path. Video footage will be subsequently analysed for the purpose of counting all *Nephrops* and their burrows. Sampling will follow that of the trawl survey.

The objectives of the combined survey are the estimation of *Nephrops* abundance and biomass, catchability (for the research trawl gear) and the relationship between sediment characteristics and *Nephrops* densities and size distribution.

4.1.6 New Zealand (NIWA) photographic surveys

Photographic surveys for *Metanephrops challengeri* have been conducted in New Zealand using a drop frame camera system since 1998 (Working Document 7, Annex 2). A random stratified approach is used, with strata defined by depth bands and latitude within the core area of a fishery, as determined from catch and effort logbook records. Sampling strata are shown in Figure 4.6. Positions of stations within strata are randomized using RAND_STN (v 1.7 for PCs; MAF Fisheries 1990) arbitrarily constrained to keep the midpoints of all stations at least 1 km apart. In the early years (1998 – 2002), surveys consisted of 20 or more stations, each station of 2–5 (usually 3) transects, and each transect of (nominally) 12–15 photographs. Within a station, transects were spaced about 1000 m apart at roughly constant depth, such that each station mimicked a short trawl tow (the original intent of this design was to compare photographic and trawl methods of sampling scampi). In the 2003 surveys (and since), a shortage of time, and the results of a study of the effects of spatial distribution of scampi burrows on survey design and efficiency (Watson and Cryer, 2003), led to the use of a single transect of (nominally) 40 photographs at each of the stations, with surveys consisting of up to 42 stations. Within a station (or transect), photographs are taken as the ship drifts, using a time delay sufficient to ensure that adjacent photographs do not overlap. The camera system includes a timing circuit, which originally triggered the camera to take images at a 60 second interval, but which now can be preset to take photographs at 20, 40 or 60 second intervals. The system is currently set to a 40 second interval, to increase the number of images to a given deployment time, but during all surveys, consecutive images are regularly checked for overlap (to ensure the drift speed is sufficient to prevent image overlap with the timing interval).

In addition to the photographic sampling, trawling is conducted at some of the stations (generally the first two stations selected in each strata), to provide information on the length and sex composition of the population, and an index of trawl survey catch rate. Trawl tows are of 3 nm length.

4.2 Advantages and disadvantages of designs

Traditional random or random stratified designs may result in poor geographical coverage of the ground in some years, owing to the random nature of station locations. To address this concern, a number of surveys have adopted either a random fixed grid design, or a random design stratified by a grid or combination of grid and sediment strata. Geostatistics provides a method for estimating the variance conditional on the sample locations and as such provides the ideal method for determining the relationship between survey design, the locations of the samples, and the precision of the estimate (Rivoirard, *et.al.*., 2000). However, time and the expertise available at the meeting did not allow a detailed analysis of the various designs with geostatistics. The advantage of the fixed grids design, depending on the resolution, is that it reduces the concerns about poor coverage, and potentially provides a more appropriate survey dataset of geostatistical analysis approaches. The main disadvantage is that with fixed grids there needs to be adequate coverage. Where there is a problem with coverage e.g. 2003 for the Aran grounds (Working Document 2, Annex 2) the resulting estimate may not be that accurate.

Ideally, survey simulations would be conducted, taking into account known *Nephrops* distribution and variability in density for each stock. It is possible that that optimal design will vary between stocks.

4.3 Simulation testing

One area of uncertainty in the *Nephrops* TV survey process is the appropriate level of sampling effort to apply to a stratum in order to obtain an accurate and precise measure of burrow density. A simulation was carried out using the 2006 Cefas Farn Deeps survey data. This survey was chosen as it samples 90 stations within a single sediment stratum.

Random selections of between 11 and 90 burrow density values, without replacement, were made, and mean burrow density calculated from these selections. This process was repeated 10000 times for each number of burrows selected. The median mean density, along with the 5 t^{h} and 95 t^{h} percentile values are shown in Figure 4.7.

The median mean burrow density remains stable, as would be expected when carrying out so many random samples. The 5th and 95th percentile show a smooth curve centring on the median value, with little evidence for skewing of the distribution. This is indicative of bootstrapping on normally distributed data.

As a normal distribution is a requirement of the Students t-distribution used to calculate confidence limits about the mean burrow density, which are then raised to give error bounds on the population size estimates, a better approach may be to test for the number of samples required to consistently satisfy this requirement.

The bootstrapping process was repeated, this time testing whether the random selection of burrow densities was normally distributed, using a Shapiro-Francia test (Royston, 1993). A significant proportion of random samples produce normally distributed density values once a sample size of 46 is reached (Figure 4.8). This suggests an accurate estimate of abundance could be made using approximately half the sampling effort.

The Farn Deeps area is further stratified into arbitrary rectangles to ensure adequate spatial coverage. There is significant variation of burrow densities between rectangles (Figure 4.9); however, there were between 2 and 13 samples taken per rectangle, making a resampling simulation on this scale impractical.

The median mean value of 10000 average burrow density calculations using random samples of 46 burrow densities is 0.5867 (CoV 0.5600), compared to 0.5865 (CoV 0.5603) using all 90. This suggests carrying out more than 46 samples does not make a significant improvement to the accuracy of burrow density estimates.

The WK recommends that similar evaluations of all surveys should be carried out to see if survey effort can be reduced without a loss in precision or accuracy.

4.4 Adaptive survey design

Some initial investigations into adaptive survey designs for *Nephrops* surveys were presented to the ICES SGNEPH in 2000 (ICES, 2000). The following section is taken from this report.

In conventional stratified random sampling, the population is divided into strata and a random sample is selected in each stratum, with selections in one stratum being independent of selections in every other. To obtain the best estimate of the population total with a given total sample size, optimal allocation of sample size among the strata involves using larger sample sizes in strata that are larger or more variable. Often one does not have prior knowledge of the stratum variances. It is therefore natural to consider computing sample variances from an initial part of a stratified survey and to use these estimates to adaptively allocate the remaining samples among the strata. Designs such as these are referred to as adaptive designs. Secondary sample allocation can also be based on sample means, rather than variances, since with many natural populations high means are associated with high variances. Adaptive approaches were adopted for the underwater TV surveys carried out in the Firth of Forth and Moray Firth in 1999. The overall survey area for each of the grounds was divided into a grid of sub-units, and two stations were allocated on a random basis within each sub-unit. Where the stations were located on unsuitable ground for *Nephrops* (i.e. patches of hard ground in the middle of the Firth of Forth), a suitable site was randomly selected. The first sweep of the survey was then carried out, with burrow densities estimated “live”, and the survey route planned to finish at one end of the survey area. Burrow densities from the “live” counts on the first sweep were used to allocate stations for the second sweep. Additional stations were allocated to sub-units based on mean density, using an in-house program based on Francis (1984). For each of the strata, the relative gain G from adding an additional station was estimated

$$G = A^2.M^2 \big/ \left(n\left(n+1\right)\right)$$

where A is the area of the strata, M is the mean burrow density within the strata, and n is the number of samples from the strata. M2 is commonly found to be proportional to variance (Barnes and Bagenal, 1951; Grosslein, 1971), and either could be included in the above equation, but Francis (1984) found M2 to be more stable than variance when densities were highly skewed. An additional station was added to the strata with highest G, the value of G was then recalculated based on the additional sample (n), and allocation of extra stations continued on the same basis until all additional stations were allocated. For the surveys carried out in 1999, 40 and 34 stations were surveyed in the initial stage for the Firth of Forth and Moray Firth, respectively, with 15 stations added to both for the secondary stage. In both areas, one of the additional stations was found to be on unsuitable sediment, and excluded from final analysis. Plots of the burrow densities observed in each stage of the surveys are shown in Figure 4.10 to Figure 4.13. It can be seen that in both stocks the additional stations were located in the areas of highest density from the initial surveys. A summary of the sum of strata variances for the initial and full surveys for each stock are shown in Table 4.3. The variance was reduced for the Moray Firth, but the additional stations had little effect on the Firth of Forth survey variance. For simplicity, the algorithm used to allocate additional stations based on relative gain assumed uniform strata area, and did not take any account of different sediment types within strata. This may well have led to allocation of stations to incorrect strata to reduce the overall variance, particularly for the Firth of Forth, where the sediment is spatially heterogeneous. Since *Nephrops* is limited in its distribution to appropriate sediment types (which often occur in irregular patches), and density varies with sediment type, it may be more appropriate to use strata based on sediment information. This could be done either using a single patch as a stratum, or splitting larger patches into a number of strata, and take the exact area of the strata into account in calculating the relative gain.

Since the 2000 report, adaptive surveys have been conducted on an opportunistic basis on some Scottish surveys, when voyage logistics have allowed returning to a ground following time to analyse initial stations. The effects of the adaptive process on survey outputs in these later surveys have not been investigated. Although it is not always logistically feasible to plan a voyage to allow the return to a ground, the use of adaptive survey designs can potentially reduce overall variance in survey results, but targeting additional effort into the strata contributing most variance to the survey estimate.

Table 4.1. Summary of FRS *Nephrops* TV survey activities.

Area	Functional Unit	Management Area	Survey Basis	Stratification Type	Apprx. Stations	Notes
Arbroath	**n/a**	**I**	**Rarely surveyed**	**-**	**-**	**Low level of landings**
Clyde	**13**	**C**	**Annual (*Scotia*, Q2)**	**Sed. and Geog.**	**40**	
Deep Water	**n/a**	**C/D**	**Annual (*Scotia*, Q3)**	**No**	**-**	**Drop frame, not used in assessment**
Devils Hole	**n/a**	**I**	**Occasional (*Scotia*,Q2)**	**No**	**-**	**Overlaps mgt areas I/H**
Firth of Forth	**8**	**I**	**Annual (*Clupea*, Q3)**	**Sed. and Geog.**	**50**	
Fladen	**7**	**G**	**Annual (*Scotia*, Q2)**	**Percentage Clay**	**60**	
Jura	**13**	**C**	**Regular (*Scotia*, Q2)**	**Sediment**	**12**	
Moray Firth	**9**	**F**	**Annual (*Clupea*, Q3)**	**Sed. and Geog.**	**50**	
North Minch	**11**	**C**	**Annual (*Scotia,* Q2)**	**Arbitrary Rect.**	**40**	
Noup	**10**	**F**	**Occasional**	**No**	**10**	**Surveyed in 1994, 1999, 2005 and 2006**
South Minch	**12**	**C**	**Annual (*Scotia*, Q2)**	**Sed. and Geog.**	**40**	
Stanton Bank	**n/a**	**C**	**Annual (*Scotia*, Q2)**	**Fixed stations**	**6**	
West Coast*	**11**	**C**	**Regular (*Clupea*, Q4)**	**Set areas**	**variable**	**Not used in assessment**

Table 4.2. A summary of the number of UWTV stations, survey days and beam or trawl stations in each survey each year for the stocks around Ireland.

Grounds	Approximate area	Year	UWTV Stns	Survey Days	Beam/Trawl Tows
Aran Grounds	Aran Grounds 940 km^2 Galway Bay 41 km^2 Slyne 26 km^2	2002	61	8	0
		2003	45	8	0
		2004	76	8	0
		2005	77	8	0
		2006	73	8	3
Irish Sea	Western Irish Sea 5791 km^2	2003	166	15	24/24
		2004	147	15	24/24
		2005	144	15	24/24
		2006	144	15	24/12
Celtic Sea	Smalls only 3800 km^2	2006	118	10	10

Table 4.3. Sum of strata variances for initial and full surveys for Moray Firth and Firth of Forth stocks.

	Initial survey		Full survey	
Stock	Stations	Sum of Strata variances	Stations	Sum of Strata variances
Moray Firth	**34**	**0.63**	**48**	**0.54**
Firth of Forth	**40**	**2.39**	**54**	**2.40**

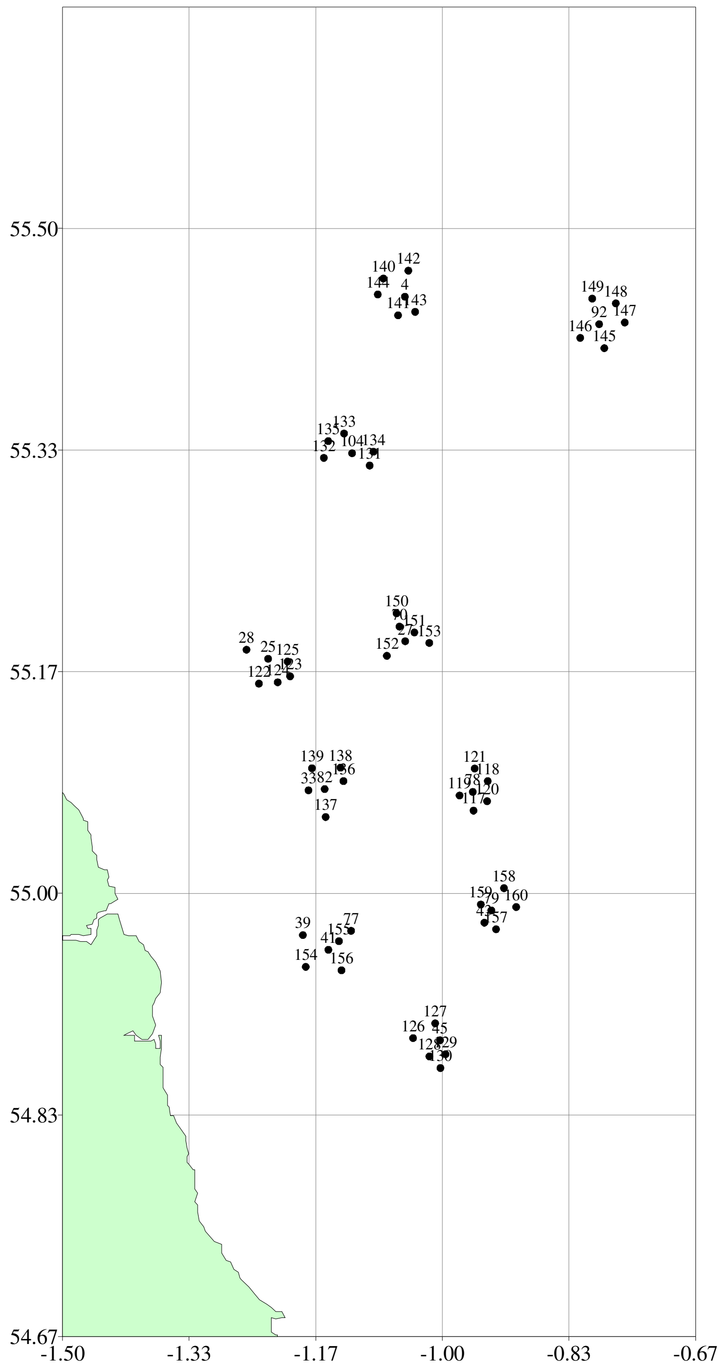

Figure 4.1. Location of additional sampling stations for spatial study October 2001 and March 2002.

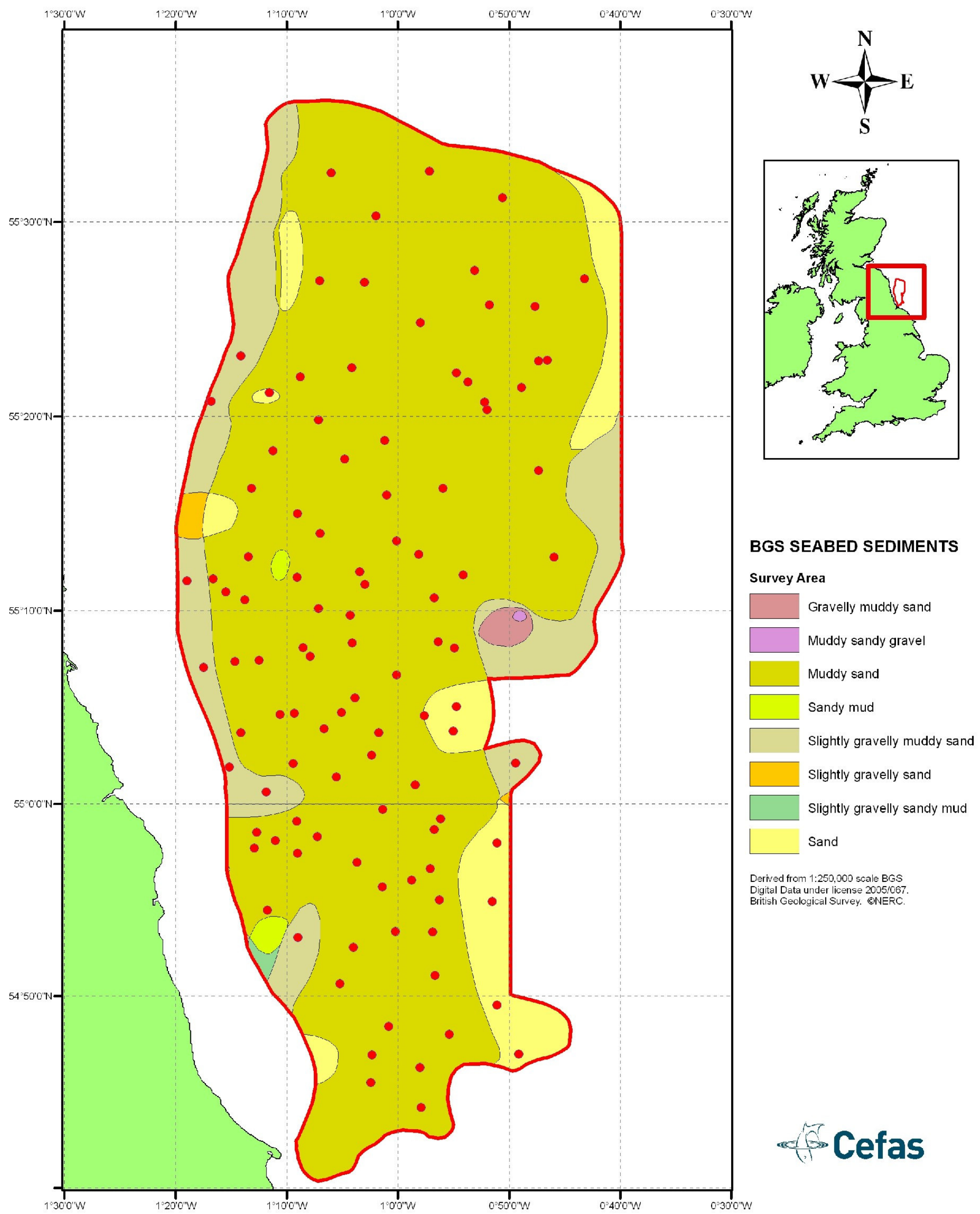

Figure 4.2. Location of sampling stations for standard Cefas Farn Deeps UWTV survey. The sediment types as defined by British Geological Survey within the survey area.

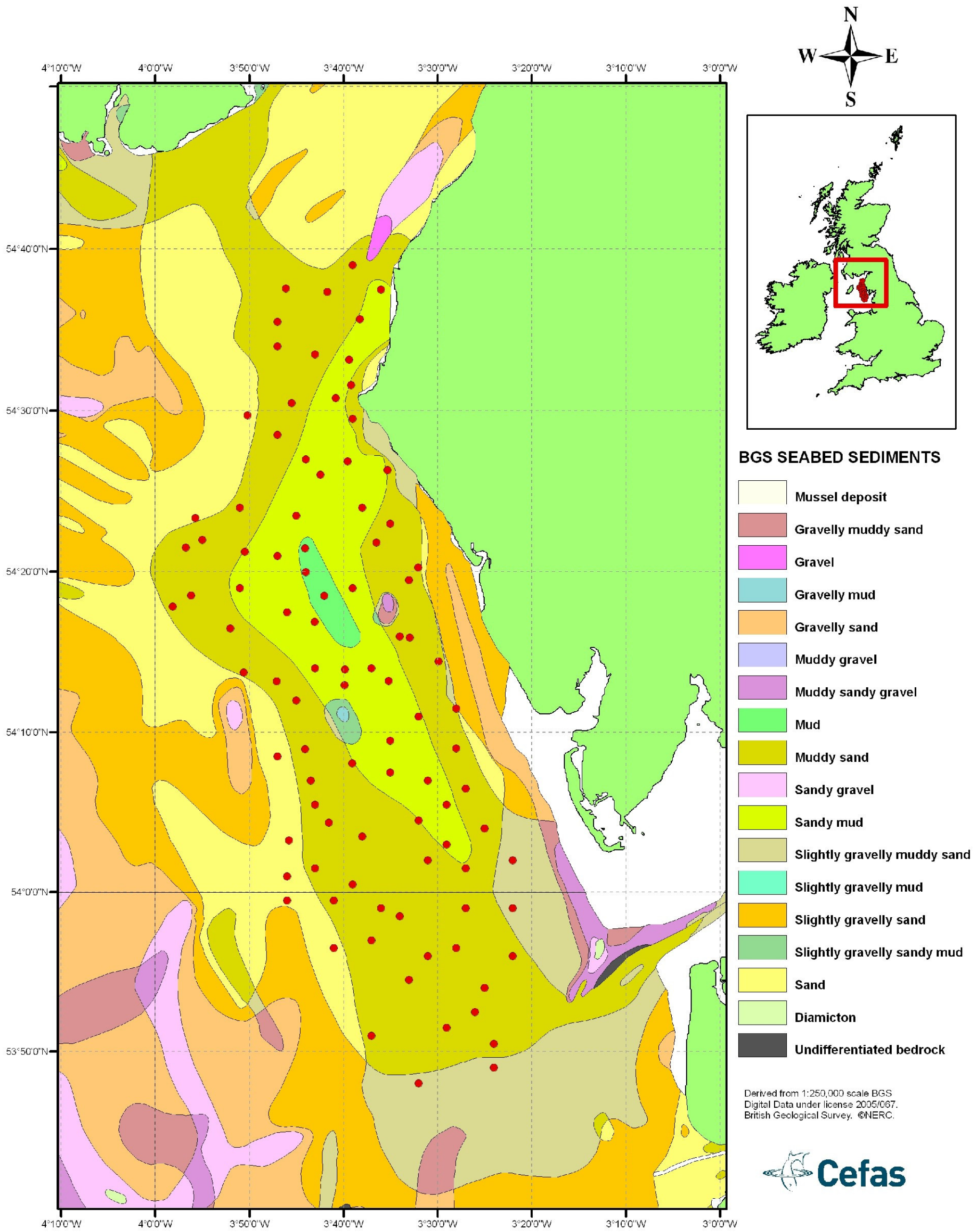

Figure 4.3. Location of sampling stations for Cefas Eastern Irish UWTV survey. The sediment types as defined by British Geological Survey within the survey area.

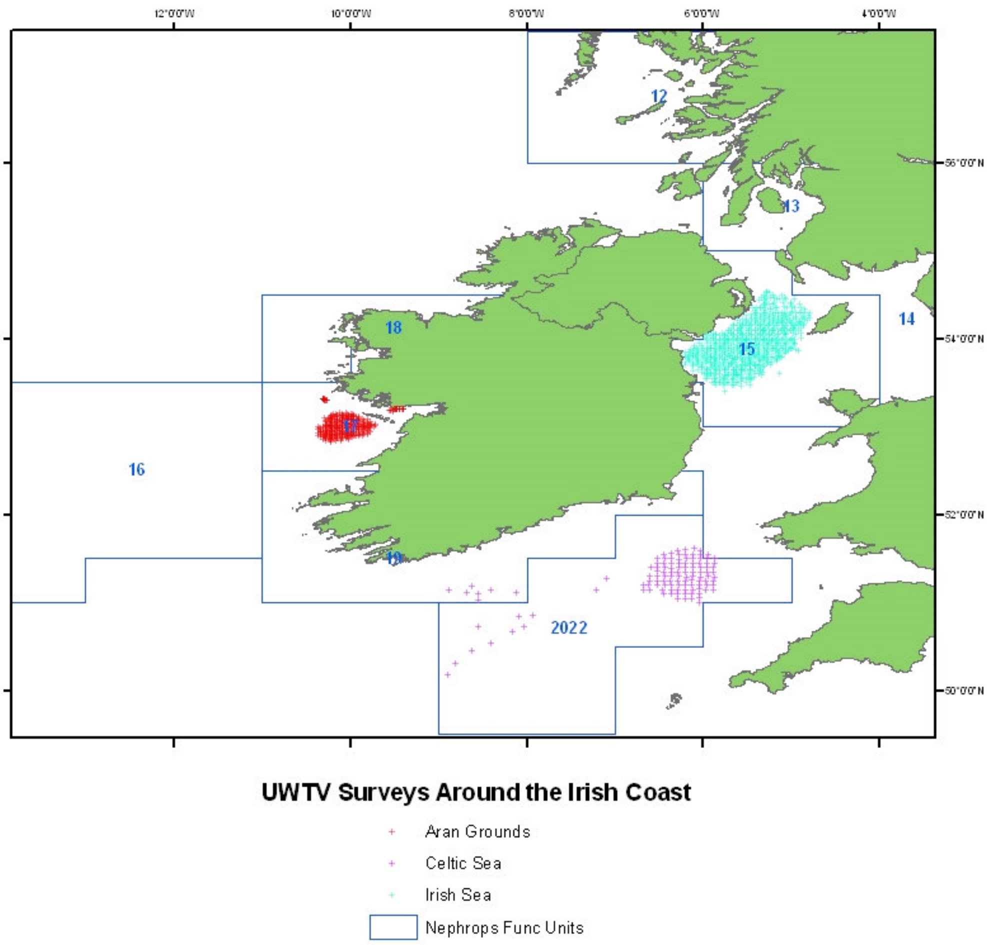

Figure 4.4. The distribution of station for Irish UWTV surveys in 2006 of the Aran Grounds (FU 17), Celtic Sea (FU 20–22 and some stations in FU19) and the joint Ireland-Northern Ireland survey 2006 in the Western Irish Sea (FU15).

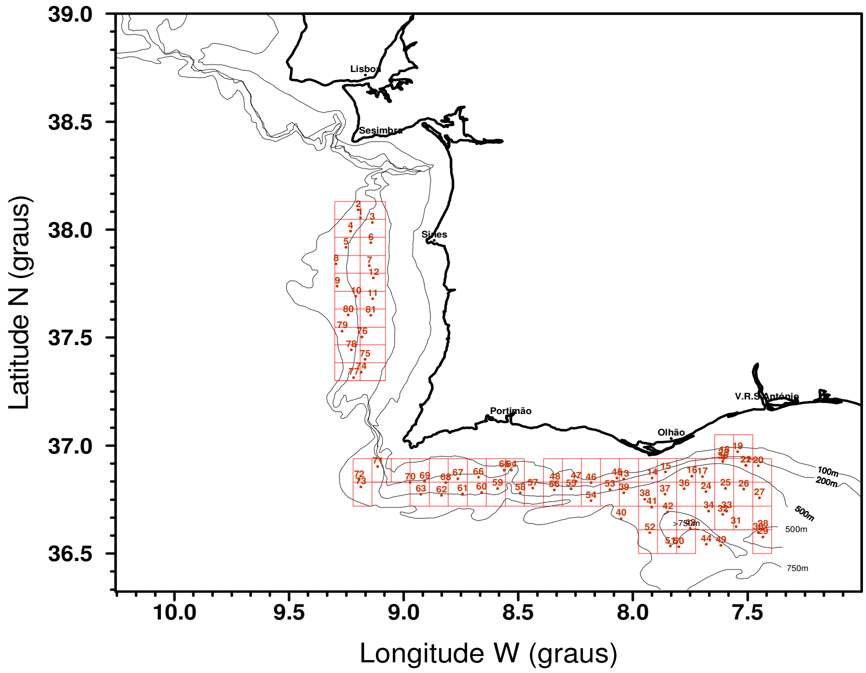

Figure 4.5. Regular grid used since 2005 in Portuguese Crustacean Trawl survey.

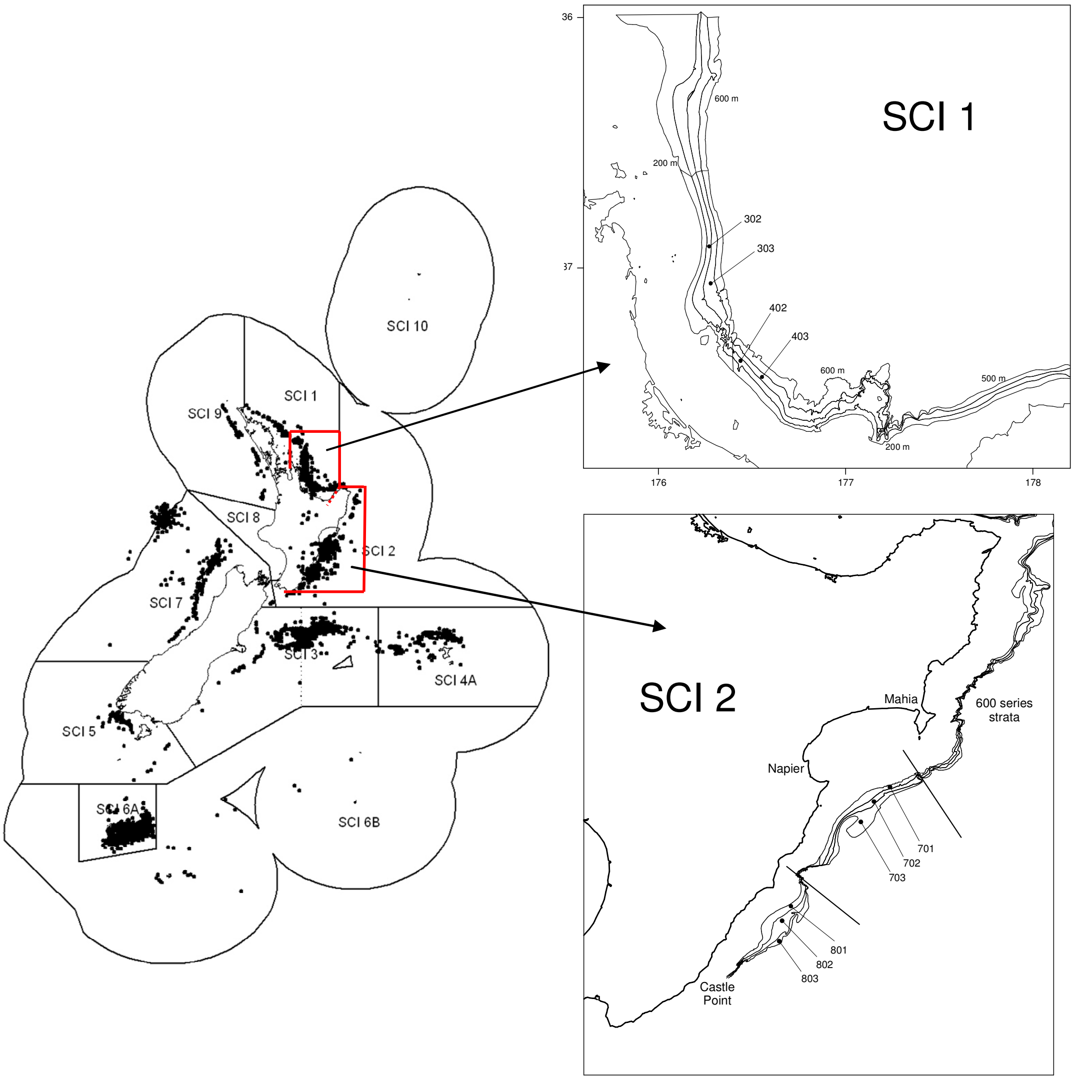

Figure 4.6. Fishery management areas and the locations of the main fishing areas for scampi, *Metanephrops challengeri*, in New Zealand waters. Dots indicate start positions of all trawl tows targeting scampi on Ministry of Fisheries catch/effort databases to the end of the 2004–05 fishing year. Insets show sampling strata for the photographic surveys of scampi and scampi burrows in the SCI 1 and SCI 2 fisheries.

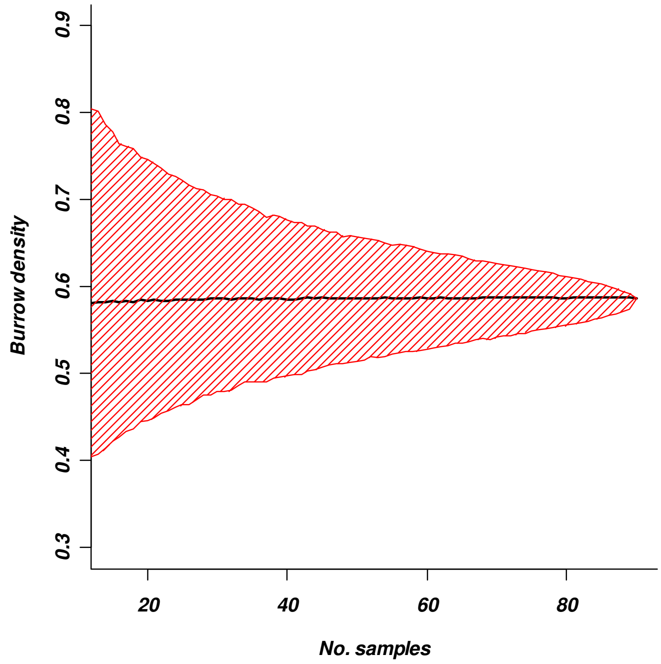

Figure 4.7. Median mean burrow density, surrounded by 5 th and 95 th percentiles for Farn Deeps sandy mud strata, calculated from 10000 random samples (without replacement) of between 15 and 90 burrow densities.

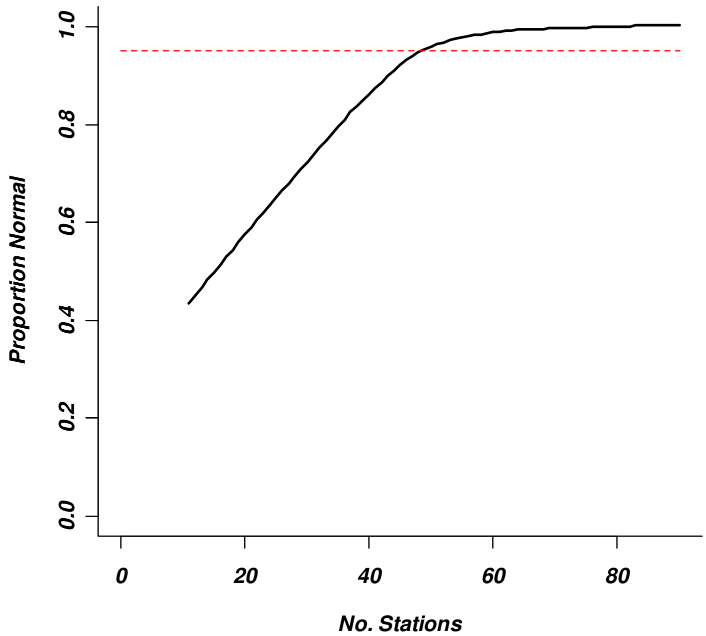

Figure 4.8. Bootstrapped estimation of the number of stations required to produce a normal distribution of burrow densities 95% of times.

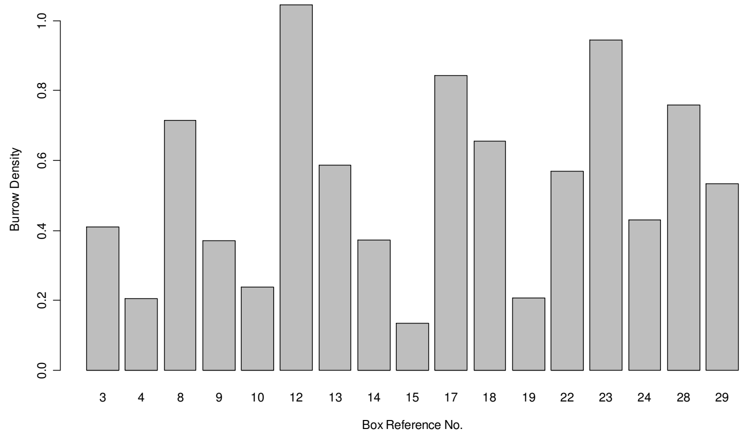

Figure 4.9. ***Nephrops*** **Burrow densities of arbitrary strata rectangles in Farn Deeps, 2006.**

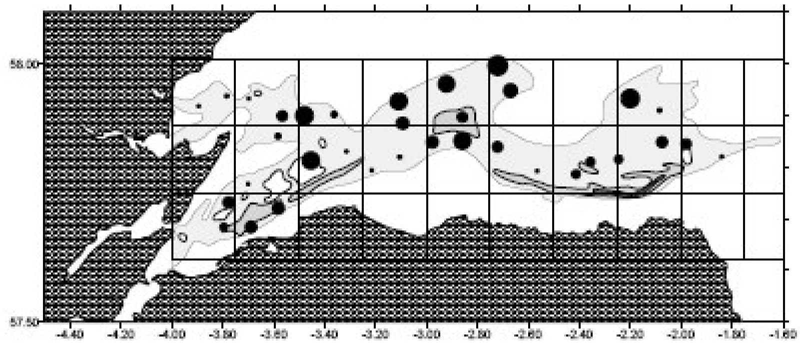

Figure 4.10. Map of TV stations for initial Moray Firth survey (size of dot scaled to burrow density).

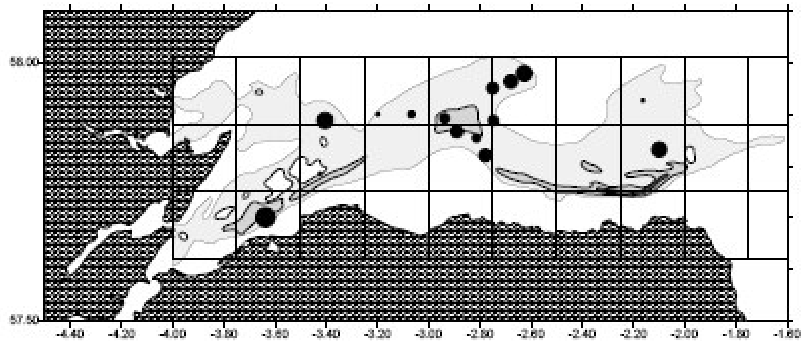

Figure 4.11. Map of additional TV stations for second stage of Moray Firth survey (size of dot scaled to burrow density).

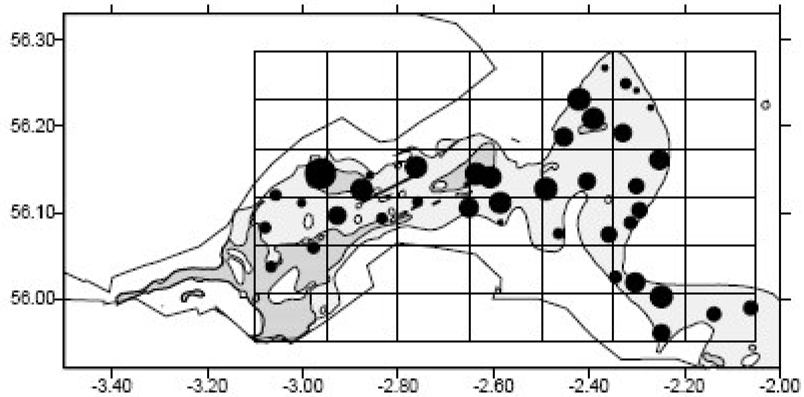

Figure 4.12. Map of TV stations for initial Firth of Forth survey (size of dot scaled to burrow density).

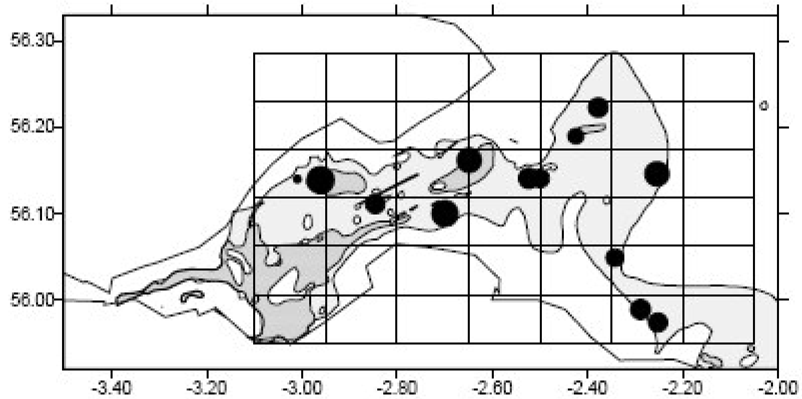

Figure 4.13. Map of additional TV stations for second stage of Firth of Forth survey (size of dot scaled to burrow density).

5 Survey methodology

5.1 Review of existing protocols

At the meeting the standard operating procedures (SOPs) of England and Wales, Scotland, Ireland, Northern Ireland and Greece were made available and reviewed. There was considerable heterogeneity in approaches and levels of details in these documents. Given the large volume of information it was decided not to include the SOPs for each country in the report. These are available form the individual countries on request. It was recognized by the group that SOPs were and integral part of all UWTV surveys ensuring the quality and reproducibility of data collected. It is recommended that the guidelines for quality assurance conform to the standards outlined in Rumohr (1999) and in “Techniques in Marine Environmental Sciences” (ICES, 2004). Here the main procedural differences, QA and QC issues, data storage, and training needs specific to *Nephrops* UWTV surveys are discussed.

5.2 Counting procedures

5.2.1 Where?

Both Ireland and Scotland are now completing all burrow counting while still at sea. English counting has generally been performed back in the laboratory but is moving towards also counting at sea. The main advantage to counting at sea is that the staff is already devoting their time to the task and reading the footage back in the laboratory will incur additional costs to the project. Given the many and varied work pressures once back in the laboratory there can be a significant time-lag between the collection and reading of the video footage and significant time would be required to re-achieve the burrow counting mind-set, whereas at sea people are immersed in the relevant work.

There are, however, potential draw-backs to counting at sea which the group identified. Sea-state may influence the concentration and therefore consistency of counters, and this effect could be investigated with a specifically designed experiment during a cruise. The generally long working time during research cruises may also affect the ability to concentrate and the time of day allocated to reading compared to other duties may also be a significant influence. Counting at sea relies upon the number of trained staff able to participate in the cruise. Counting at the laboratory may be able to draw on a wider base of trained staff and would mean that any key staff unable to participate in the cruise could still be utilized.

Results of comparisons between counters working in isolation and concurrently (Working Document 9, Annex 2) demonstrated a significant decrease in individual counting rate and harmonization of variance when working together. It was expected that there would be a reduction in overall variance, whereas in fact the counters became more conservative in their criterion for what constituted an individual burrow complex. These results suggest that counting is best performed in isolation.

5.2.2 What and how?

Within a tow the majority of laboratories count burrow complexes, the number of *Nephrops* observed in burrows and the number of *Nephrops* observed on the surface. The decision of which burrows contribute to a single burrow complex is, of course, highly subjective. The alternative of counting individual burrow entrances is less subjective although species identification remains a subjective call. Data exist regarding the number of burrows openings which make up a complex, this is for a relatively low density, shallow environment and it is unclear how this would translate to the majority of commercial grounds.

Most laboratories record individual burrow complexes as they pass over the bottom of the screen, although some laboratories use a line a few centimetres up from the bottom of the screen. The raised line has the advantage of giving a wider field of view and hence smaller edge effect, but means that the burrows are smaller and less visible at the point of counting and therefore users are more likely to miss small entrances.

In instances where only part of a burrow entrance crosses the counting line, these are counted only where some of the shadow (i.e. the actual hole) is visible. In cases where the hole disappears off the vertical boundaries of the screen but the "scrape" in front of the burrow remains visible, these are NOT counted.

Irish and Scottish protocols divide each 10 minute tow into 1 minute blocks and pause playback of the tow after each minute to record the three counts, plus information regarding any time the image was imperfect (obscured by sediment, sledge flying etc). The English counts are for the full 10 minute tows. Dividing the tows into 1 minute blocks has the advantage of increasing the data for statistical analysis and when burrow densities are particularly high (i.e. 50 burrows per minute) gives the readers a respite; a full 10 minutes counting at that rate would risk within-count fatigue. Each time the video is paused; details are written to paper records and subsequently transcribed to computer.

Counting in high-density situations may be facilitated by slowing down the video footage; however, attempts to do this with standard footage were largely unsuccessful due to the degradation of the image at slow speed. In order for slowed-down replay to be useful, higher quality footage would be required.

Live counts (i.e. while the sledge is actually on the seabed) are undertaken by all labs although the results are rarely used. These counts have been used in instances of recording equipment failure, but the counters are multi-tasking during the actual recording process and concentration on counting is not 100%. Live counts are also checked in instances where large discrepancies in the re-counts are observed.

Working Document 9 (Annex 2) identified the presence of day effects in individual's performance (i.e. counting consistently above or below average) and it may therefore be advisable that each tow an individual counter is allocated is actually counted twice, the second count on a different day. The influence of individual's day effects would be reduced by having multiple readers for each tow and this is a standard practice among the laboratories where counting is performed by a minimum of 2 persons.

Counting is normally undertaken with the use of hand-held tally counters. Direct, electronic data capture systems such as those used on finfish surveys save significant amounts of time with regard to data entry and removes the potential for transcription errors. The differences in the survey data-streams between finfish surveys and TV means that direct data capture systems are unlikely to be applicable for TV surveys. Touch-sensitive screens or digital whiteboards may be one way forward although the footage speed required would be much slower than is currently used in cases of high abundance. The exercise undertaken by Cefas (Working Document 9, Annex 2) recorded burrow counts directly to computer, each entry being time-stamped so that inter- and intra-user burrow identification could be analysed. This was a very simple system which did not allow for users to change their minds and retrospectively remove an entry.

5.3 Tow duration

All TV tows undertaken by England, Scotland, Ireland and Northern Ireland are intended to have a duration of 10 minutes. Investigations carried out previously (Afonso-Dias, 1998) concluded longer tows (providing conditions remained constant) did not significantly improve the accuracy of abundance estimates. However, the length of the tow can vary due to environmental factors. Under certain conditions tows are shortened (e.g. at the edge of grounds in the Irish adaptive surveys). In Scotland, recordings of less than five minutes are usually discarded. If conditions throughout the run vary considerably (for example, sustained periods of zero visibility due to sediment disturbance or the sledge flies off the seabed) additional minutes are added to the end of the run.

Analyses presented in Working Document 9 (Annex 2) demonstrated that the mean count was normally established after a short period and underwent little change after 5 minutes, the underlying data being counts every 15 seconds. Cumulative variance also remained relatively stable after 5 minutes. A further analysis was undertaken by the Group using the minute by minute counts provided by Scotland and Ireland.

Cumulative mean counts were calculated for each reading of each individual tow. These were then standardized to the mean cumulative count for that reading of that tow. Figure 5.1 shows the log of the standardized cumulative counts for 9 different areas, 6 Scottish and 3 Irish (data from 2006). These areas were chosen as they had more than 20 stations. There is a clear reduction in the variability of the counts at around 5–7 minutes after which it increases again. One other interesting feature is a systematic negative bias in the first 3 minutes of counting in the Scottish data. These results are, however, based upon raw counts and no account of survey area has been made. The negative bias in the Scottish data may therefore be a result of a systematic change in vessel speed through the tow rather than a systematic change in burrow counting efficiency. Counts adjusted for field of view and vessel speed (i.e. density) were available from Ireland and the log standardized results are given in Figure 5.2. While the mean count is stable through the all the series, there is clearly a reduction in variability with a minimum around 5–7 minutes. The subsequent increase in variability is more pronounced in the raw counts compared to the area-adjusted densities indicating that variability in vessel speed in the latter portion of each tow is a significant factor. There is still a slight increase in variability in mean count after about 7 minutes and this may relate to the scale at which *Nephrops* tend to form discrete patches on the ground.

The analyses presented here suggest that tow counts could be conducted over time spans of less than 10 minutes and that this may in fact decrease uncertainty in the density estimate of each tow. The results, particularly the Irish ones, are for very high density sites. In instances of particularly low density, the full 10 minutes may be required to get sample sizes large enough to overcome integer artefacts. While it would be possible to reduce the tow time by a few minutes where live-counts indicated that the density estimate had stabilized variance, the savings in cruise time would be minimal given the time taken to deploy and retrieve the sledge. Time savings would be better achieved during the counting process and restricting the time viewed on each tow where sufficient densities were observed. These time savings could then be put back into the system to cover the time which will be required for the quality assurance and calibration procedures which are currently lacking in the existing protocols.

5.4 Quality control/quality assurance (QA/QC)

The use of TV footage for stock assessment is comparatively new compared with catch-based analyses used in finfish and the current level of QA/QC is relatively low. It is acknowledged that all components of assessment surveys should have established procedures which are enforced to ensure the quality of data acquisition, collection, handling and analysis, and of subsequent reporting. In-house Quality Assurance manuals should be developed in accordance with appropriate national and international standards and followed rigorously (Rumohr, 1999, ICES, 2004). Such manuals should include procedures for

- handling survey equipment.
- station selection and location, as well as navigational accuracy and documentation.
- survey report writing and documentation.

- detailing the appropriate qualifications and training of survey and laboratory personnel including training for screen evaluation/counting.

Currently each laboratory compares the counts for each tow from the multiple users and in instances where there is a large disparity (>20%) the tow is the re-read by another user. While this process picks up some anomalies, random testing of apparently consistent counts should also be undertaken. Statistical advice should be sought on the appropriate level of re-counting. Validation of the electronic records must be undertaken by comparison with the paper records.

At present in New Zealand, reader bias is examined within a generalized linear modelling framework on burrow count data from individual images, with a Poisson error distribution. Canonical indices for reader, year and stratum are calculated from the GLM indices and covariance matrix following Francis (1999).

The "bias correction" factor for each reader (C_i) is defined as follows

$$C_i = \frac{\bar{c}}{c_i}$$

where c_i is the index of the ith reader, and is the average of the reader indices. Corrections are applied by multiplying counts by the appropriate reader factor.

Inter-laboratory comparisons are currently undertaken on an *ad hoc* basis and are not as rigorous as they should be.

Reference sets should be developed for each stock (or group of stocks with similar features), and should encompass the range of burrow densities and conditions (e.g. water visibility, sledge speed, variability in sledge altitude) encountered and considered acceptable for use within the surveys. It is not yet known which conditions affect burrow counting accuracy and further work will be required ahead of the creation of the reference sets to determine the key factors. A statistical exercise should be undertaken to determine the degree of complexity required in the production of personal calibration coefficients, it may transpire that water visibility has a different effect on a counter's reliability at high and low burrow densities.

Each video clip within the reference set need not be the full duration of the original run as it only needs to be representative of the conditions. It is more important to have numerous short clips covering the range of conditions and may include duplicates of individual clips to assist with analysis of consistency. Several reference sets should be created with the individual clips in a randomized order so that repeat observations of the reference sets are statistically robust. Reference sets would need to be re-created when changes in equipment are proposed, in particular upgrading to higher resolution cameras. In this instance both the new and old cameras would need to be run at the same time and a calibration exercise undertaken between counts from both systems.

Uniformity of approach in the identification of burrow systems is important but so is uniformity in the identification of burrows from species other than *Nephrops*. Considerable expertise in this field exists and it is important that there is effective knowledge transfer. It is suggested that initially a burrow identification workshop is convened, the product of which would be a reference set of video clips of *Nephrops* and non-*Nephrops* burrows for training purposes.

The most experienced and consistent readers from several different laboratories should then generate a set of standard counts for the reference sets, against which all other readers and future surveys are calibrated.

5.5 Data storage

Burrow count data are handled in a variety of ways by the different laboratories, including databases and spreadsheets. Owing to the different ranges of equipment deployed by the various laboratories, a common database format would not be appropriate for data storage at this stage, however a simplified data-exchange format based on the simplest datasets would be advantageous for the sharing of data and inter-lab consistency exercises. Down the line there is recognition that making DCR-funded survey data available more widely is a requirement for funding and more efforts will have to be made to have a uniform data model and central repository for this category of data.

In Ireland, a survey database has been developed and trialled to initially manage the count and navigational data (Figure 3.1.9). This will allow the development of quality control tools to analyse and QC the data on the fly during the survey.

The storage of video footage is not straight-forward. Historical analogue footage (Umatic, SVHS) has either already been digitized or is in the process of being digitized. DVD is currently the most common format for video storage although there are concerns regarding the lifespan of individual discs and it is recommended that DVDs are re-created every 1–2 years. Given the large number of DVDs generated in a single year (50 for Scotland), this becomes an increasingly burdensome task. Alternative digital formats are being tested including optical drives and server-quality hard drives.

Data from New Zealand trawl and photographic survey stations are stored in the Ministry of Fisheries Empress database *trawl*. Original and annotated photographic images are held as lightly compressed JPEG files on a secure, backed-up server and in three additional copies on CD-ROM at two different NIWA sites. Copies have also been provided for the Ministry's Data Manager at Greta Point (Wellington), as part of contract requirements. Image details and records of readings are centralized in a formal MS-Access database on a secure, backed-up server at NIWA Auckland. These are copied to the Ministry's Data Manager at Greta Point on completion of the project.

5.6 Calibration and training

Intra-laboratory calibration is currently *ad hoc* and involves new staff sitting in with experienced staff as they explain their burrow identification criterion and demonstrate these in action. Training should not, however, be restricted to new incumbents but should be a regular occurrence for all staff. Experienced counters may show within-year consistency, and even consistency over 2–3 years but longer term trends in their criteria would not be detected.

The creation of the reference datasets as outlined in section 5.4 will make the process of inter- and intra-laboratory calibration much more rigorous. Calibration of individual counters should be undertaken at least once a year and preferably at least once during the burrow counting exercise. Each reference dataset will

Previous surveys will also need to be calibrated against this reference set, either through recounting the entire survey (which would be very time consuming), or (where the original readers are still available) a random selection of stations, for which comparisons can be made with the original counts to calibrate with counting consistent with the reference set. Procedures may already be available from the otolith counting community, but if not, will have to be developed in conjunction with statisticians.

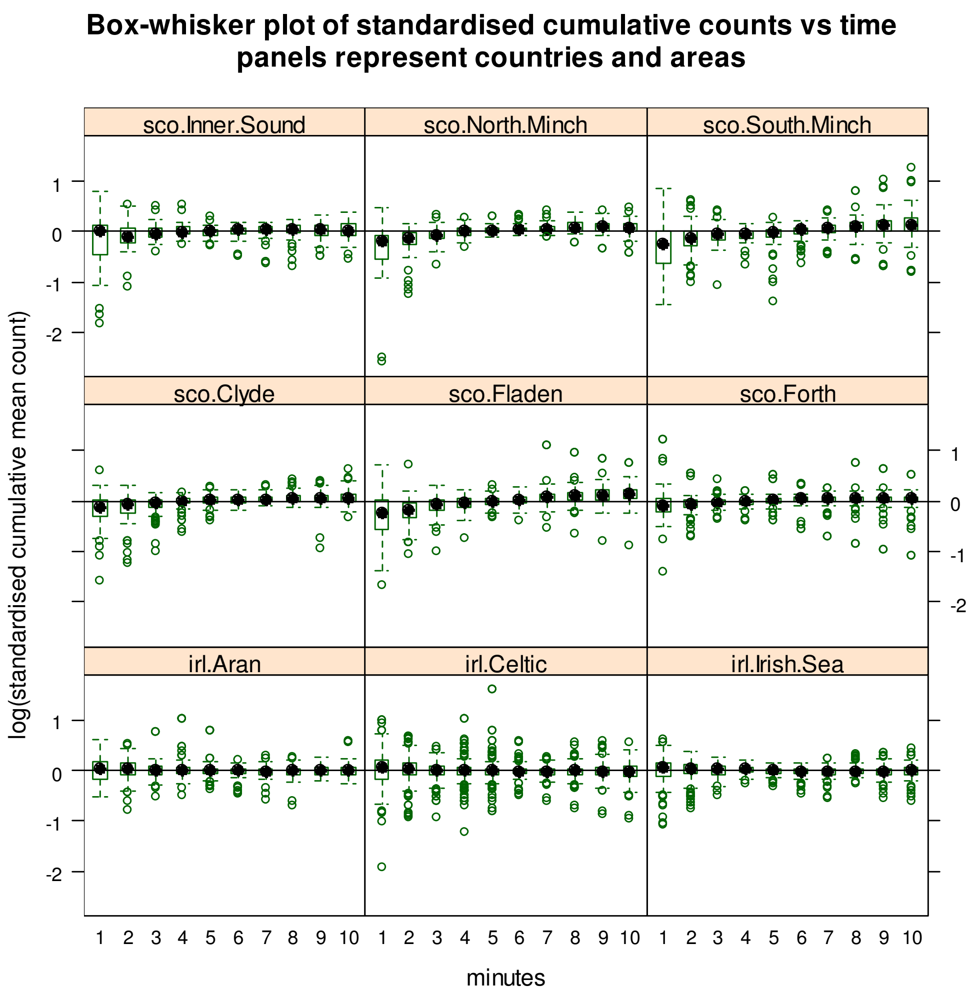

Figure 5.1 Log(Standardized cumulative mean count) for Scottish and Irish survey areas where more than 20 stations were sampled. Solid points indicate the mean value, boxes cover 75% of the data and open circles show outliers.

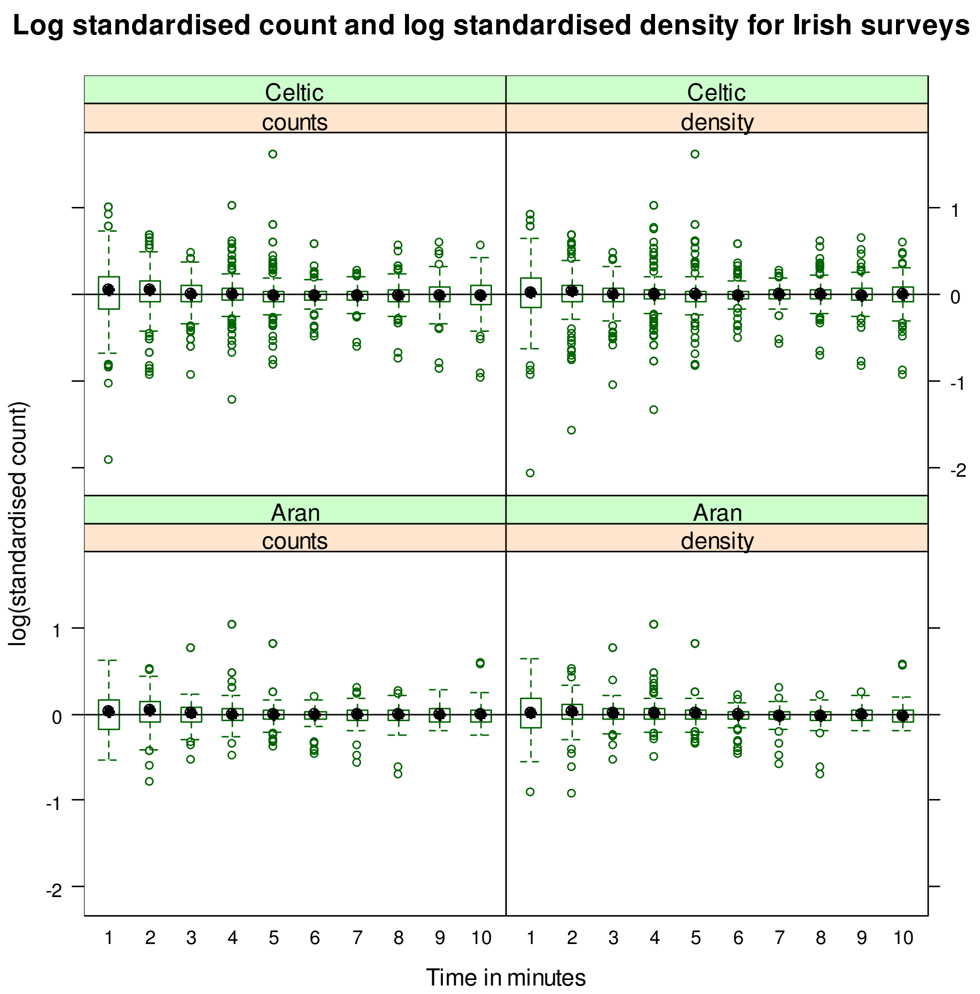

Figure 5.2 Log(Standardized cumulative mean count) and Log(Standardized cumulative density) for two Irish survey areas. Solid points indicate the mean value, boxes cover 75% of the data and open circles show outliers.

6 Translating surveys into abundance estimate

6.1 Calibration field of view

6.1.1 UK-FRS Approach

The FRS TV sledge incorporates a rangefinder (altimeter), which has shown that the height of the sledge varies considerably over the course of a TV run and that sinkage of the sledge into sediment varies between survey areas (Figure 6.1). The relative positions of the rangefinder and camera on the sledge are known, allowing the height of the camera, and hence the field of view, to be calculated throughout the run. The rangefinder logs a height every 4 seconds to a recording PC. The data file generated by the PC is imported by the work-up software and an average height for each minute of the run derived. This is used to calculate mean viewed width for each minute, which is multiplied by the distance travelled, as measured by the odometer and logged in the same data file, to give an area for the "ribbon" which was viewed. It should be noted that this method assumes that the camera is horizontal to the seabed, whereas in reality the sledge and camera is likely to be lifting at the front where it is towed.

The significance of this approach was investigated by comparing the 2005 assessment of the South Minch (functional unit 12) stock, which incorporated data from the rangefinder, with a second assessment using the same data, but with a fixed rangefinder height of 88 cm (assuming a 4 cm sinkage of the sledge into the sediment).

This comparison showed that having assuming a fixed height did not have a significant influence on burrow density estimation (Table 6.1), but produced consistently higher estimates of density. When these density estimates were raised to the strata areas, the assessment using a fixed height produced a biomass figure of approximately 1000 tonnes greater than that using the variable height (Table 6.2) – this equates to around 1.7% of the total biomass.

These results suggest that a precise measurement of field of view is not critical to the assessment process, providing a good approximation is made.

As the height of the rangefinder appears more variable in the Fladen data, a more detailed exploration of these data were carried out. Only 3% of runs had a mean height of 0.88 m or less (Figure 6.2).

A comparison was made between the calculated viewed area using the average rangefinder height over the whole run, a 1 minute average as used in the work-up routine, the actual height logged at 4 second intervals and an assumed height of 0.88 m (Figure 6.3), which allows a 4 cm sinkage of the sledge (Table 6.3).

This suggests that assuming a fixed height based on the parameters of the sledge, without accounting for the possibility that the sledge may rise off the bottom, can lead to an underestimate of the viewed area by up to 25%, causing an overestimate in burrow density.

6.1.2 UK-Cefas

On each survey the sledge field of view is calibrated at the start and end of the survey. Gauged weld mesh is fixed to the bottom of the sledge runners to fill the cameras field of view when in the water. The sledge is re-deployed and the width and height of the recorded field of view at the bottom of the TV screen determined.

To address concerns about the apparent variation in the real field of view within a tow and between tows, a laser scalar array has been constructed in house to be mounted around the camera. This projects four dots onto the seabed. This should provide a scale and perspective to be able to calculate the field of view at the bottom of the TV screen at each station and within tows.

6.1.3 IR- MI

The field of view is estimated as follows for MI UWTV surveys assuming that the sledge is flat on the seabed (i.e. no sinking) Working Document 2. For each survey a known distance is marked on a rope. The rope is then attached to the sledge skis onboard such that the rope appears at the bottom of the TV screen. A measurement in water is then taken from the bottom edge of the screen. The calculation is given as:

= (Mark on Rope/Rope Mark in water)*Camera Screen.

The field of view has been calculated as 72 cm for MI UWTV surveys.

With the upgrade of the towing umbilical there should be scope for improved instrumentation of the sledge to calibrate the field of view more accurately. (Note: since the meeting lazers have been successfully used on the 2007 surveys to confirm the field of view estimates)

6.1.4 Other approaches (GR-HCMR, IT-ISMAR, UK-UMBSM)

The simplest but least precise method for calibration of the field of view is recording a bottom grid *in situ*, or at least when the system is immersed. This grid can be superimposed over the video display. Each institute does this in a slightly different way but the end result is the same. Sight of the sledge runners may also give a further calibration point for width of view. In some applications a calibration tape has been stretched between the runners (ISMAR). In the case of HCMR, laser spot measurements (at least two parallel spots of known separation) may also be used in a similar way to the grid. Improving laser technologies now allow for parallel lines or grids to be projected and these may solve the calibration of field of view more accurately optically (e.g. http://www.tritech.co.uk/products/products-seastripe.htm). Crossing of sledge tracks can give information on the amount of sinking and indicate whether any calibration adjustments need to be made. In the case of UMBSM, sledge sinking has been investigated by divers on some occasions.

6.2 Monitoring distance over ground

6.2.1 UK-FRS method

To record the distance travelled by the sledge, two methods are used: the ship's position and an odometer. Two recordings of the ship's position are made. The first is directly from the on-board navigational data, which has an accuracy of three decimal places of a degree. This is recorded by a PC along with data from sledge data, time and date. The second version of the ship's position is supplied by a stand alone Garmin 75 GPS unit. These data, accurate to four decimal places of a minute, are recorded on a separate PC, and provides a detailed track of the ship's route over small distances (e.g. coral or habitat work).

A more accurate method uses an odometer attached directly to the rear of the sledge. It is these data that are utilized in the work up programme. This aluminium wheel (manufactured by FRS) has a circumference of 1 metre, and on each full rotation, a magnet passes over a sensor which sends an electrical signal to the Range Finder, which in turn sends the readings to the ship, where it is demodulated and recorded on a PC. The magnet and transmitter system was designed and supplied by Remontec UK (www.remontec.co.uk), and was originally part of the company's T-count system for measuring the amount of cable being paid out through towing blocks, and has a maximum depth rating of 900 m. The wheel is mounted on an arm at the rear of the sledge, which can be raised and lowered from controls on the ship. This means that when the sledge is coming in to range of the seabed, the raised wheel is in an upright position and does not become the first point of contact with the strata, which could damage the mountings. It also allows for the wheel to be lowered further if there is any sea swell and the sledge rises off the seabed. By lowering the wheel further than normal, the rotating section is in contact with the sediment more often, providing a more accurate distance reading. The effectiveness of the odometer is constantly monitored by a rear facing video camera, with a live feed to the ship.

6.2.2 UK-Cefas

The survey provides four estimates of distances that are calculated and used to confirm or estimate the final distance run by the sledge:

- Sledge distance – the distance over the ground travelled by the sledge between the start and end of the count. Calculated from logged DGPS strings.
- Ship distance – the distance over the ground travelled by the vessel between the start and end of the count. Calculated from logged DGPS strings.
- 'Crow' distance – the distance between the DGPS reading at the start and the end of the count as the crow flies.
- Odometer distance – the difference between the meter wheel reading at the start of the count and the reading at the end of the count.

With the exception of the odometer distance, the distances are calculated using elliptical trigonometry (Reference: subroutine Seavec from a Woods Hole Oceanographic Institute Programme). Both the odometer distance and Crow distance are calculated from the details displayed on the Video overlay.

The Tower CEMAP Hydrographic system uses: the time and ordinates from DGPS, the ships head from the Gyro, and response from the HIPAP transponder on the sledge to calculate and log the sledge and ships positions and logs them at programmed intervals. The output is processed to determine the ship and sledge distances. The calculated distances between each logged position from the start to the end of the count are summed. The tracks of both sledge and ship are plotted and reviewed, and any obvious outliers and errors removed refining the distance. Comments are entered if there are any concerns about the apparent tracks. The distances are compared and the more appropriate distance flagged. In the first instance the sledge distance is used unless there are concerns about the track in which case the ships track is considered. If neither track is good enough the odometer distance is compared with the crow distance; the behaviour of the odometer on previous tows in relation to the ship and sledges track is considered to determine a best estimate for distance. To help with the comparisons - any affect on distance run caused by changes in warp length or water depth is also displayed. Both depth and warp length are recorded at the start and end of the count.

6.2.3 IR-MI

For MI UWTV surveys conducted in 2002–2004, DGPS position of the vessel was used to determine the distance over ground travelled by the sledge; for each tow this was logged to text file via MS Hyper-terminal. Since 2005 IXSEA GAPS (Global Acoustic Positioning System) has been employed to track, in real-time, the video sledge.

The various on-board navigational signals referred to in Section 3.1 are bundled into Starfix Navigational Suite and the ship, sledge- USBL and sledge-layback position are outputted as a text file (for mapping analysis refer to 3.1 Review of Systems). The behaviour of all navigation data is monitored onboard to ensure there are no data anomalies by the surveyor. The sledge-layback position is the estimated position of the sledge when the warp paid out has been included.

Mapping of the three navigational outputs allows for the verification of the behaviour of the ship, sledge and layback Figure 6.4. From this analysis the most appropriate distance over ground for the tow track is selected. Normally, when available, the USBL distance over ground is used. This is calculated in the MapInfo GIS Package. This smoothes out any later variations due to noise in the “SPOT” corrected DGPS signals. The crow-flies distance over ground is calculated by minute interval for each tow. The area for each tow is then calculated. Where counting conditions become untenable, the discounted minutes their associated distance and area calculations are then removed from the analysis.

6.3 Burrow identification and accuracy

6.3.1 Recognition criteria and factors influencing accuracy

Nephrops burrows must be accurately recognized and adequately counted. A number of burrow features are species-specific for *Nephrops*. These relate to the shape and appearance of burrow openings, the size and angle of tunnels, the geometric relationship between openings, and features such as tracks adjacent to openings (Chapman and Rice, 1971; Atkinson, 1974a; Chapman, 1980; Tuck *et.al.*, 1994; Marrs *et.al.*, 1996). A crescentic opening to a shallowly descending tunnel, with obvious linear tracks fanning out from the opening is characteristic of *Nephrops*, but not all openings to *Nephrops* burrows have these distinctive features. In their EC-commissioned report, Marrs *et.al.*. (1996) collated literature information on 658 *Nephrops* burrows including diver-mapped information on burrow structure. Detailed structural information was derived from resin casts of nearly 150 burrows, over 130 of which are illustrated. Structural information based on video analysis of 68 deep Aegean burrows was also considered. Burrows ranged in complexity from simple unbranched tunnels with a single surface opening to complexly branched burrows with numerous openings. Some consisted of the interconnected burrows of differently sized *Nephrops*, others were connected with the burrows of one or more other species. The overall mean number of openings to a *Nephrops* burrow was three. The mean maximum distance between a burrow’s openings was 52 cm, the range 14–172 cm.

Marrs *et.al.* (1996) looked at underwater television from a range of European sites at depths from 10–450 m and indicated the species that were likely to cause confusion with *Nephrops*. A provisional key to burrows is included in their report.

Problems with identification are most likely to occur when burrows occur among a high density of burrows of other species, especially if the *Nephrops* burrows are small in size and therefore more difficult to differentiate from those of other species. Particular problems may arise where small *Nephrops* burrows occur among a high density of the burrows of the calocaridid mud-shrimp *Calocaris macandreae* or in areas where the burrowing crab *Goneplax rhomboides* occurs. Confusion over the identity of small burrows may also occur if burrowing fish such as the goby *Lesueurigobius friesii* or the snake blenny *Lumpenus lampretaeformis* are present on the ground or, in some cases possible confusion may occur with the burrows of the laomediid mud-shrimp *Jaxea nocturna*. If the red band fish *Cepola rubescens* occurs among *Nephrops* burrows this is another source of potential difficulty for the inexperienced observer. On some grounds stomatopod and alpheid burrows may be present and necessitate observer vigilance. Other species may also cause problems and this may be compounded where the burrows of other species are joined to those of *Nephrops* (see Marrs *et.al.*., 2006). However, in all cases careful observation of species-specific burrow features will reduce the uncertainty. Fortunately, on most grounds *Nephrops* burrows can be identified with a high degree of confidence, and for the larger burrows there is rarely any doubt. Burrow counters should make themselves aware of the species that may cause confusion on their ground and endeavour to be as accurate as possible. Published information on the structure of burrows that maybe encountered on grounds is summarized in Marrs *et.al.* (1996). Other summaries of relevant literature are found in Atkinson (1986), Atkinson and Taylor (1988, 1991) and Hughes and Atkinson (1997). For detailed information on species that may cause particular differentiation difficulties on some grounds see Rice and Chapman (1971), Rice and Johnstone (1972), Atkinson (1974b), Atkinson *et.al.* (1977, 1987), Nash *et.al.* (1984), Nickell and Atkinson (1995) and Atkinson and Pullin, (1997). Further information for Adriatic grounds is given by Pervesler and Dworschak (1986), Froglia *at al.* (1997) and Atkinson and Froglia (2000).

Many of the species that burrow on *Nephrops* grounds are rarely seen. Some never leave their burrows. *Nephrops*, however, is caught commercially because of its emergence behaviour. Burrow counters should take particular note of the features of *Nephrops* burrows in which the occupant can be seen, since this will inform identification of burrows where the occupant cannot be seen. The appearance of *Nephrops* burrow openings may vary in different ground types so the burrow counters needs to "tune in". The maxim for burrow identification should be "if in doubt, leave it out". Therefore burrow counts should be conservative. The implication of this is that abundance estimates based on burrow counts will be conservative, but this is preferable to overestimation.

Marrs *et.al.*. (1996) found that counters could be quite variable in their ability to count *Nephrops* burrows from videotape. However, they were mainly interested in comparing videotape counts with absolute numbers of *Nephrops* burrows derived by divers who were experienced in observing *Nephrops* burrows. The divers followed the TV sledge tracks. At one relatively straightforward site where burrows were easy to identify the results of the divers and the more experienced of the counters were in agreement. At another more complex site the divers' results differed significantly from those of the counters who analysed the video taken on the same tracks. Variation could be as both undercounts and overcounts. The most populated transect was undercounted by the videotape counters. In some cases the divers were able to identify with certainty *Nephrops* burrow openings for which the surface observers had doubt and therefore ignored, and they also identified burrows whose openings were so orientated to the lights that they were poorly illuminated and therefore overlooked by the surface observers. However, it was also clear from the diver record that burrows had been misidentified as *Nephrops* by the videotape observers. The results indicate that great care has to be taken when counting burrows from the video output, even when this is done by trained observers.

6.3.2 Terminology

Ichnologists (a branch of palaeontology) who study trace fossils and animal-sediment relationships of living organisms to aid the interpretation of ancient traces have defined bioturbation structures such as burrows and their components (see Frey, 1973). For such workers burrows components such as shafts (approximately vertical), tunnels (mainly horizontal), etc. have precise meanings. Such workers also differentiate between burrows and burrow systems, the former being simple and the latter being complex burrows. In the *Nephrops* assessment literature the term "burrow system" has a different meaning and refers to the single burrow that can be deduced from a configuration of openings that are judged by the observer to be interconnected. Many who work on burrows prefer to use the term "opening" for a burrow aperture, rather than "entrance", because the latter has behavioural implications that may be inappropriate (see Atkinson and Taylor, 1988).

6.4 Occupancy rate

Marrs *et.al.* (1996) examined burrow dynamics and longevity at field sites where over 200 marked burrows featured in various aspects of the study. Some burrows, although changing in configuration, remained as entities for several months, in some cases for as long as 11 months. However, these grounds were not fished during the investigation. The burrow cast collection indicated the dynamic nature of burrow configurations, with evidence of new tunnels under construction and old ones in a state of collapse so that burrows 'migrated' slowly through the sediment.

Marrs *et.al.* (1996) presented field data showing that, even at an unfished site, many burrows were vacated by the occupants and subsequently silted up and collapsed. In the absence of sight of the occupant, several features were indicative of occupancy (e.g. fresh tracks, signs of recent excavation), but these were not infallible. Also, partially collapsed burrow sections or debris in openings were no guarantee that a burrow was unoccupied.

The site investigated by Marrs *et.al.* (1996) had several unusual characteristics. One was that vacated *Nephrops* burrows were taken over by black gobies (*Gobius niger*), and these appeared to maintain the burrows. These will not feature on more typical, deeper *Nephrops* grounds. There was also a tendency for *Nephrops* to disperse in the winter at these sites (probably moving to the more stable conditions of adjacent deeper water), perhaps accounting for some of the unoccupied burrows. During the study several burrows were encountered that were co-occupied by two adult *Nephrops*, a phenomenon also reported by Chapman and Rice (1971).

A number of studies have drawn attention to the association between the burrows of adult and juvenile *Nephrops* (see Chapman, 1980, Marrs *et.al.,* 1996). Where recognizable on video, such burrows are usually counted as a single burrow. This is a reasonable approach because the juveniles are not represented in the fishery. Should attempts be made to separately consider such burrows, great care is necessary because other species can also associate with *Nephrops* burrows and have a similar appearance to adult-juvenile burrows to the untrained eye (See Atkinson 1974a; Atkinson *et.al.* 1982; Marrs *et.al.* 1996).

Within the Bayesian length based model being developed for *Metanephrops challengeri* in New Zealand, occupancy is considered along with detection rate as factors that combine to generate a catchability term for photographic surveys (see section 7.3 and Working Document 7), relating observed abundance to the population estimated by the model. No studies investigating burrow occupancy have been conducted for this species, and one approach considered has assumed informed priors derived from the investigations of *Nephrops norvegicus* presented by Marrs *et.al.* (1996).

At present, data on occupancy of *Nephrops* burrows on typical fished grounds are lacking.

Cefas is currently constructing a remote lander with programmable camera and plans to place it over burrow systems to take time-lapse video and collect observations of emergent *Nephrops* over 12-hour periods. This will help to answer concerns about occupancy although it will take some time for the dataset to be large enough for any analysis to be conclusive. Similarly, in Ireland there is a plan to have a long term observation site with and AVU to look at occupancy and other behavioural observations on the Aran grounds.

6.5 Edge effects

Burrow counts will include burrows wholly in view of the camera and burrows that extend out of the field of view. Such burrows would therefore be counted again on an abutting parallel camera track. Allowance must be made for such burrows if, rather than providing an index of abundance, the count is used to give a number per unit area which will then be used in computations to yield an abundance or biomass value for the ground.

Marrs *et.al.* (1996) and Smith *et.al.* (2003) reported the results of an attempt to investigate edge effects in the Aegean using the program Distance. This was time consuming and complex to apply and is now not considered to be the best solution to the problem. An alternative approach is considered below. The following section is extracted almost verbatim from ICES (2000) and arose from a workshop held at Lowestoft in 1999 (Addison and Bell, 2000).

Following the discussions at the Lowestoft meeting, two approaches were taken to examine the implications of "edge effects" on estimation of burrow density within the existing burrow counting methodology. Burrow density estimation on known densities was simulated at MLA with different widths of view and burrow extents, while at UMBSM edge effects were estimated from actual seabed video.

6.5.1 A simulation of "edge effects" in the underwater TV method of *Nephrops* abundance estimation

This work describes a simulation exercise to investigate the "edge effects" introduced in the current practice of counting burrow systems along a narrow transect of seabed, defined by the width of view of the camera system employed. Throughout this work, a *Nephrops* "burrow" is defined as a system of interconnecting tunnels, and an "opening" is an individual hole associated with a burrow. An individual burrow may have several openings. Estimates of density for a given station are derived from a *Nephrops* burrow count for a known viewed area (width of view * length of track). All *Nephrops* openings identified in the field of view are allocated to a burrow, and burrow count is used to estimate density. Openings are allocated to burrows by experienced counters in a subjective manner, based on burrow orientation and distance apart. Calibration exercises have shown that there is a high degree of similarity in allocation of openings to burrows between the various laboratories involved in *Nephrops* underwater TV assessment. Clearly, it is not possible to know how much of a burrow viewed within a transect extends beyond the viewed area. The counting methodology currently employed, counts the burrows of all openings viewed, and therefore, those burrows that extend beyond the field of view will introduce some degree of edge effect to the counts, by overestimating the density of burrows in the viewed area. A pictorial simplification of the counting methodology is provided in Figure 6.5.

A simulation exercise was undertaken to investigate the potential edge effects of the current burrow counting methodology. This initially investigated the effects of burrow density and field of view. Using data from resin casts of *Nephrops* burrows collated by Marrs *et.al.* (1996), a random burrow population was simulated. The maximum distance between openings (MD cm) in the burrow was drawn from a ln normal distribution (mean 3.843, st dev 0.432), while the number of openings was drawn from a Poisson distribution (2 + mean 1.39). It was assumed that the minimum number of openings a burrow could have was two. Burrow centres were then randomly located within a 4*250 m area, to generate the required density. A random spatial burrow pattern was assumed. Field studies suggest that *Nephrops* burrows may not be randomly distributed at all times of the year (Tuck *et.al.*, 1994), but for simplicity a random distribution has been assumed for this exercise. For each burrow, the first opening was randomly located on the circumference of a circle (centre randomly located above) with diameter equal to MD, with the second opening being opposite the centre from this. Any extra openings were located randomly within this circle. A count was then made of the number of burrows with an opening within the viewed area (width of view *200 m, a typical track length for Scottish surveys), and a density calculated. One thousand simulations were carried out for each combination of width of view (0.6, 0.8 and 1.0 m) and burrow density (0.1 to 1.5 m^{-2} in 0.1 m^{-2} increments). Following this, the importance of edge effects for different burrow sizes were also examined. No significant relationship has yet been identified between burrow density or animal size and maximum distance between openings (Marrs *et.al.*, 1996), possibly due to the limited range of population densities which occur in diveable depth, and have therefore been available for resin casting. However, there is a non-significant positive relationship between animal size and burrow length (Marrs *et.al.*, 1996), and anecdotal observations appear to suggest that in certain low burrow density stocks (e.g. Fladen Ground) burrows may be far larger than those observed in higher density stocks (e.g. Firth of Clyde or Firth of Forth). Therefore, the mean of MD was varied in further simulations (from 0.4 – 1.2 m, in 0.4 m steps). It is likely that the standard deviation of MD would vary with the mean, and in the simulation, the two parameters have been assumed to be directly proportional. MD was assumed to be constant within an individual simulated track. Because of the difficulty in analysing very large files, the number of density increments was reduced (0.1 to 1.3 m^{-2} in 0.4 m^{-2} increments). For each simulation, the proportional error of the density estimate was calculated from:

Proportional error = (Estimate – Density)/Density

The effects of width of view and burrow density on proportional error in the first simulation (burrow size drawn from a single distribution) were examined within an ANOVA framework. A full model (both variables as factors, with an interaction term) was fitted, then simplified to a minimum adequate model using a stepwise selection procedure employing AIC. The minimum adequate model is shown in Table 6.4, with width of view retained as a factor (2 d.f.) and density as a linear term. Mean proportional error remained constant with burrow density, but was inversely related to width of view (reducing from 0.57 for 0.60 m, to 0.43 for 0.80 m and 0.34 for 1.0 m). The standard deviation of the proportional error was inversely related to both width of view and burrow density. The model including variability in burrow size was analysed in the same way as the initial model. The minimum adequate model is shown in Table 6.5, with burrow diameter, density and width of view retained as factors, and the burrow diameter: width of view interaction term also retained.

Figure 6.6 shows plots of proportional error in relation to burrow density and burrow diameter.

For a given burrow diameter, the proportional error was constant with burrow density, but was inversely related to the field of view. Proportional error increased with burrow diameter. The standard deviation of proportional error was inversely related to burrow density and width of view. Proportional error in burrow density estimates varied from 0.30 (mean burrow diameter 40 cm, 100 cm field of view) to 1.18 (mean burrow diameter 120 cm, 60 cm field of view). This simulation suggests that the current techniques employed in burrow counting have the potential to overestimate burrow density. Although within the simulation the proportional error was constant with density, *Nephrops* are generally smaller at high densities (due to slower growth), and one might expect burrows to be smaller, reducing proportional error. Using the mean burrow size from resin casts (Marrs *et.al.*, 1996), density is overestimated by between 34% and 57%, depending on the field of view. While TV density data are used solely to generate an index of abundance, edge effects are unlikely to introduce large errors (provided the mean size of the burrows or the field of view does not change). If the data are used to estimate stock biomass, however, then both edge effects and appropriate mean size values should be taken into account. Both of these factors could lead to considerable overestimation of TSB.

6.5.2 Estimation of edge effects from seabed video

Nephrops burrows (not individual openings) were counted from 10 minute segments of viewable videotape taken at each station. First the segment was viewed and a rough count generated (familiarisation). The segment was then analysed at minute intervals and burrows that were judged to be wholly in the field of view (i.e. ‘crossed’ a 1 m wide reference line viewed on the monitor) were counted (A). This was done twice and the mean count taken. Following the above count for a given minute, the section of videotape was viewed again and the burrows that were judged to extend out of the field of view (i.e. only part of the burrow visible at the reference line) were counted (B). Again, the mean of two counts was taken. Results are shown in Table 6.6. Traditional counts are A+B and this results in overestimation when burrow densities are raised to be representative of the ground. A + B/2 is a crude attempt to account for edge effects.

Thus the potential overestimates due to edge effect ranges from 25–34% (excluding the low-density site that generated 50%). Earlier work (Marrs *et.al.*., 1996) where underwater TV tracks were dived and *Nephrops* burrows within the viewing area counted by the divers showed that, whereas there was reasonable consistency between counters, the true number of burrows present was consistently slightly higher. This is because counters of video records do so conservatively; if the identity of an opening is in doubt, it is excluded. Also some burrows are almost invisible to counters since their openings are directed away from the camera. The two approaches resulted in similar conclusions, in that edge effects for the camera configuration used in Scotland (approximately 1 m width of view) lead to an approximate 30% overestimation of burrow density (for a mean burrow system diameter of 40 cm). While the burrow density estimates are used as an index of animal abundance, such refinements may not have great influence, but as more reliance is put onto stock biomass estimates generated from TV abundance, it will be important to take such effects into account.

6.5.3 Summary Points

- Edge effects mean that surveys are potentially overestimating density by underestimating effective viewed area (width) of track.
- This is a potential source of bias and uncertainty.
- The magnitude of effect will vary with the size of burrows and the width of view, with the effect being greater with larger burrows and narrower field of view.
- Modelled and empirical data suggest a similar magnitude of effect.
- Edge effects are not routinely applied to assessment surveys.
- Modelling should be refined to provide correction factors that can be applied to the survey data. Refinements should include variations in burrow size and density.
- To inform modelling the edge effect, more information is required on burrow sizes from a range of grounds.
- Research to date suggests detection underestimates burrow density, and may compensate for edge effects.

6.6 Boundary uncertainty

The accuracy of definition of the boundaries of suitable *Nephrops* habitat, which is required to calculate the domain area, is a further source of uncertainty to be considered when trying to use the surveys as an absolute abundance estimate. There could be large uncertainty where grounds are extremely heterogeneous. Various new technologies and datasets have recently been used to determine boundaries more accurately and to calculate the surface area of *Nephrops* habitat more accurately. Various acoustic survey methods e.g. multibeam and side-scan can be use to construct more detailed maps of bathymetry and habitat type. Improved knowledge of the spatial distribution of fishing activity using VMS or other on-board loggers has also been used to help define or confirm the position of ground boundaries. In addition, increased resolution of ground truthing data such as using grab samples will also improve boundary definition.

The way the densities change close the boundaries may be a potential source of uncertainty that is not taken into account in the stratified random approach. It this case the assumption made is that there is a knife-edge change in mean density at the boundaries of strata and the outside the strata the density is zero. That may be a valid assumption although gradual transitions are also likely.

In the geostatistical approach used for the stocks around Ireland the survey grid is continued past the boundary until the counts are zero or a zero count is assumed. Therefore, the tendency towards zero is a function of the model used and the uncertainty is to some extent included in the survey uncertainty estimate. Working Document 3 examined environmental variables that may be important in determining burrow density throughout the Western Irish Sea. This type of approach is very promising and could lead to improved stratification and survey design. It should also be possible to further develop the geo-statistical approach to co-krig the observed densities with other variables such as sediment composition, depth, fishing effort, etc. Time did not allow for this to be progressed further at the workshop.

A further consideration to mention is the three-dimensional nature of the seabed. The ground would have to very steep or undulating a lot if this is to have an effect. At this workshop the area of the Celtic Sea ground was calculated at the surface and taking into account the three-dimensional nature of the seabed from a krig grid of bathymetry data from multibeam. The two estimates differed by less than 0.0025%. It was concluded that this is unlikely to be a major problem in most areas and can be readily estimated and corrected for if necessary.

6.7 Estimating animal size

6.7.1 From Video

6.7.1.1 GR- HCMR methods - Direct estimation of *Nephrops* size

Depending on the technologies available sizing of *Nephrops* could be undertaken to various degrees of precision e.g. categories (large, medium, small), bands (e.g. <30, 30–40, 40–50, 50–60, >60 mm carapace length), centimetre or millimetre size measurements. Direct measurements (either carapace length or total length) can be undertaken only for individuals visible on the sediment surface, preferably in profile from the side or above. It may be possible to size individuals from partial measurement where there is a known relationship with body morphology (e.g. measurement of claw length, carapace length derived from known relationship of claw to carapace length). Direct measurements will most likely be limited to larger individuals and it will unlikely to be able to differentiate between males and females.

The simplest but least precise method for direct measurement is from a calibrated field of view on screen. A bottom gird has been recorded in front of the camera view and this can be superimposed over the video display. The size of animal can therefore be estimated from the grid. Laser spot measurements (at least two parallel spots of known separation) can also be used in a similar way to the grid, although accuracy is low away from the spots and there is little information on distance away from the camera, making oblique measurements impossible. The addition of further lasers may make the system more accurate (e.g. Tritech VMS/ISS camera system) and software may be available to construct an accurate grid for oblique measurements in the plane. More complex are stereo camera systems (photogrammetry), that again may be calibrated to allow measurements to the millimetre range (e.g. Tecnomare TV-Trackmeter). Research work on software algorithms using optical flow measurements between subsequent video frames may be another source of measurement in the future.

6.7.1.2 GR- HCMR methods - Estimation from burrow size

From various pieces of observational and experimental work, relationships have been derived concerning burrow dimensions and occupant size either through direct measuring openings and the occupant or through resin casting (Chapman and Rice 1971, Rice and Chapman 1971, Marrs *et.al.*, 1996). It may be possible to estimate individual size from measurements of burrow openings obtained from video using the relationships derived form experimental fieldwork. Smith *et.al.* (2003) used Scottish relationships to try and predict size from video in the Aegean, but could not relate burrow size with mean *Nephrops* size (trawl caught) and this may be ground or area specific and requires more research with respect to the relationships and comparison of different grounds.

6.7.2 Using Still Camera

6.7.2.1 NZ – NIWA

The vertically mounted still camera survey approach employed in New Zealand for scampi surveys makes the measurement of animal and burrow sizes more straightforward than obliquely mounted video systems.

For all photographic abundance surveys, length-frequency distributions are estimated. The numbers of animals observed are generally low, and their sizes are potentially biased by emergence patterns, and so animal sizes are estimated from burrow size distributions. On each survey, the widths of a large sample of major burrow openings are measured using *Didger 3.0* image analysis software. These are converted to orbital carapace lengths using a regression of OCL on major opening width (Figure 6.7) developed using photographs of scampi clearly associated with burrows. To estimate the c.v.s at length for each year, a bootstrap procedure was used, re-sampling with replacement from the original observations of burrow width, converting each observation to an estimated scampi size (in OCL) using the regression in Figure 6.7, using an error term sampled from a normal distribution fitted to the regression residuals. Compared with the length frequency distributions from trawl catches, this procedure gave very large c.v.s, but these are thought to be realistic given the uncertainties involved in generating a length frequency distribution from burrow sizes.

6.7.2.2 Extending photographic information to estimate biomass

Estimating biomass from the photographic estimates of burrow abundance requires assumptions that all burrows (or some specified proportion) are occupied by an individual *Metanephrops*, that the length frequency distribution of those scampi can be estimated from the dimensions of the burrows, and that the average weight of an individual can be estimated from the length frequency distributions. The occupancy assumption remains untested, but the available data do suggest that burrow size increases with animal size (see Figure 6.7), permitting the estimation of population length-frequency distribution from burrow sizes. Using the population length frequency distribution to estimate mean weight requires knowledge or an assumption about the population sex ratio, given that the length-weight relationship is steeper for males than for females and that males grow larger than females. Within the approach adopted in New Zealand, it is assumed that the sex ratio (at length) in scampi caught by research trawling is indicative of that in the population (i.e. their selectivity ogives are the same). Selectivity at length is likely to be related to animal shape, and so this assumption is probably valid, although it is unclear whether emergence rates differ between the sexes. In *Nephrops*, female burrow emergence varies with reproductive state, and the sex ratio observed in catches may not reflect the sex ratio in the population (Bell *et.al.*, 2006). However, research trawl surveys have generally been conducted between January and March / April, which is likely to be the period when emergence is least affected by behavioural patterns (mature females between hatching one set of eggs and spawning the next). Amalgamating all research trawl length-frequency distributions from each modelled area (Figure 6.8) suggests that the sex ratio is about even until about 35 mm OCL for SCI 1, but slightly lower at about 32 mm OCL for SCI 2. Cryer *et.al.* (2005) assumed this point represented the size at maturity, although the pooled ovary stage data suggest size at 50% maturity may be closer to 30 mm (Tuck and Dunn, 2006). Above this size, females tend to predominate until a size of about 45 mm OCL in SCI 1 and 43 mm OCL in SCI 2. Scampi larger than this are increasingly likely to be males, although the rate of increase in likelihood appears to differ between areas. Scampi larger than 55 mm OCL in SCI 1 and 64 mm OCL in SCI 2 are almost certain to be males. This pattern, a predictable consequence of the fact that males grow larger than females, is used to weight predictions of mean weight-at-length for males and females, generating an estimate of population weight-at-length and, in conjunction with the estimated population length frequency distributions and the size of the modelled areas, an estimate of standing biomass for each year.

6.7.3 From Trawls

Various approaches have been used to estimate the size of burrow-forming animals from trawls. These include using commercial data which is potentially biased by gear selectivity, spatial and temporal factors and discarding/highgrading practices. Using concurrent survey trawls (beam or otter) may reduce these biases by using smaller mesh, a more representative sampling design and will include sampling the complete catch. The WK examined the mean size data from commercial and RV trawls for one stock (the Western Irish Sea FU 15) and calculated the impact on the deterministic biomass estimates.

In the 2006 ICES assessment the total burrow cluster count for FU15 in the 2005 UWTV survey was calculated as the mean density for non-zero stations multiplied by the estimated survey area of 5790 km^2. Zero stations were typically at or beyond the boundary drawn for calculating the survey area. The method established for the West-of-Scotland (VIa) and North Sea (IV) stocks for estimating abundance was adopted for FU15. This method consists of multiplying the number of burrow clusters by the harvest rate to give a figure of total numbers that can be removed by the fishery (adjusted for discard survival). The $F_{0.1}$ catch for FU15 was calculated using the same method to that described for stocks in areas VIa and IV and gave a harvest rate of around 20%, which was adopted.

The density estimate from UWTV surveys refers to those animals that have made the burrows counted during the survey, while *Nephrops* caught in the fishery (landings + discards) are those selected by the trawlnet and may exclude small animals that may nevertheless be large enough to make burrows, though the *Nephrops* size at which burrow building commences has not been established in the field. There is also a population of very small (0-group) *Nephrops* that do not have their own burrows and not included in the UWTV survey counts, but still form part of the stock biomass. This means there are 3 levels of the population: (a) large animals selected by the fishery, (b) all adult burrow forming *Nephrops* (c) the entire population including recently metamorphosed juveniles (0-group). This section uses data from UWTV surveys to derive and compare biomasses generated from commercially caught size composition and animals caught by the Northern Ireland trawl surveys, using a small mesh trawl.

Northern Ireland (AFBI) perform trawl surveys in April and August each year, the latter taking place immediately before the collaborative UWTV survey with the Marine Institute and also represents the time of year when there is maximum emergence of *Nephrops*. The trawl survey makes hauls of 30–60 minutes duration on a fixed grid of stations throughout the western Irish Sea. The gear is a 20-fathom *Nephrops* trawl similar to that used in the commercial fishery, but with a nominal mesh size 50 mm throughout. *Nephrops* catches are divided into male and female components and carapace length-frequency distributions measured.

Carapace length compositions of survey caught and commercially caught *Nephrops* are compared in Figure 6.9 and demonstrate a predominance of smaller animals in survey catches with a mean size of 24.8 mm CL compared with 28.3 mm CL from commercial catches (landings + discards) in 2005. Using a length-weight conversion relationship (Pope and Thomas, 1955) the mean weight of *Nephrops* caught in commercial catches during 2005 was 15.3g, compared with 10.8g from the 2005 trawl survey. Biomass estimates generated from these two mean weights and the 2005 UWTV survey abundance of 6728.97 x 10^6 give biomass estimates of 106.1kt and 69.5kt using commercial and survey data respectively (Figure 6.9 and Table 6.7).

This exercise highlights the need for caution in derivation of biomass estimates from UWTV abundance estimates. Trawl survey size composition data provides a closer representation of the total *Nephrops* biomass, though does exclude many very small animals. Although trawl surveys catch smaller animals it is also possible that some of these animals are still too small to make visible burrows. Until the size composition of animals capable of forming burrows is confirmed it would be prudent to continue applying harvest ratios to UWTV abundance data and then converted to a catch weight rather than base calculations on stock biomass estimates.

6.8 Raising procedures

6.8.1 NZ - NIWA

Burrow and scampi counts from photographs were analysed using methods analogous to those in the New Zealand Trawl survey Analysis Program (Vignaux 1994) for trawl surveys. To exclude a possible image size effect (burrows perhaps being more or less likely to be accepted as the number of pixels making up their image decreases), the approach adopted has been that images with a very small (< 1 m^2) or very large (> 16 m^2) readable area have been excluded. This has consistently been a small proportion (5%) of all images, and the proportion of unused images has reduced over the series of surveys, as control over camera altitude has improved. The mean density of burrow openings at a given station is estimated as the sum of all counts (major or minor openings or scampi) divided by the sum of all readable areas. For any given stratum, the mean density of openings and its associated variance are estimated using standard parametric methods, giving each station an equal weighting. The total number of openings in each stratum was estimated by multiplying the mean density by the estimated area of the stratum. The overall mean density of openings in the survey area was estimated as the weighted average mean density, and the variance for this overall mean was derived using the formula for strata of unequal sizes given by Snedecor and Cochran (1989):

For the overall mean, $\bar{x}_{(y)} = \sum W_i . \bar{x}_i$

and its variance, $s^2{}_{(y)} = \sum W_i^2 . S_i^2 . (1 - \phi_i) / n_i$

where $s^2_{(y)}$ is the variance of the overall mean density, $\bar{x}_{(y)}$, of burrow openings in the surveyed area, W_i is the relative size of stratum i, and S_i^2 and n_i are the sample variance and the number of samples respectively from that stratum. The finite correction term, $(1 - \phi_i)$, was set to unity because all sampling fractions were less than 0.01.

Separate indices are calculated for major openings, for all visible scampi, and for scampi "out" of their burrows (i.e. walking free on the sediment surface). The minor sensitivity of the indices to the reader "bias" is investigated with "correction factors" calculated for each reader, and a "corrected" density index for major burrow openings provided (see QA section). Confidence in the overall estimates is examined through a bootstrapping procedure, re-sampling stations (with replacement) within strata, selecting one reader (from three) within station.

6.8.2 UK-FRS

FRS calculates burrow densities using purpose written software routines. These have recently been converted from FORTRAN to R, allowing greater integration with our sediment mapping codes. These routines require the input of a working directory, in which to look for and write files, and the name of an index file, which contains details of the sledge set-up and the names of the files which contain the verified counts and logged data taken from the sledge.

6.8.2.1 Index File Structure

The index file is a text file which contains details of the survey, such as area surveyed and physical parameters of the sledge, as well as a list of the count and data files to read in.

0805S	-	Survey code
FL	-	Area code (Fladen)
90 108 9223.557.62 43.60	-	Camera parameters
72	-	No. sites in file
FL05001.dat	-	Logged data file 1
FL05001.txt	-	Verified count file 1
FL05002.dat		
FL05002.txt		
FL05003.dat		
FL05003.txt		
(Etc.)		

The sledge parameters are, respectively, height of the front of the camera, height of the rear of the camera, height of the rangefinder and length of the camera, all in centimetres, followed by vertical and horizontal fields of view of the camera, in degrees. The code then reads and loads each pair of count and data files, as given in the index.

6.8.2.2 Verified Count Files

The burrow counts for each observer are collated in a single spreadsheet, together with comments regarding the visibility in each minute of the run. Where there is no visibility for a portion of a minute and the sledge is moving (as indicated in the logged data file) the burrow count is raised to a whole minute. Where there is no visibility in a minute of the run, a “NA” is entered, which allows the code to discount that minute when calculating densities.

The finalized spreadsheet is then condensed to a single text file with four columns, giving the identification number for each run, the minute of the run and the burrow count for each observer. An additional piece of code then takes this text file and creates an individual file for each run.

The format of the count files is as follows:

11			-	No. of lines to read in		
0 0			-	2 zeroes (FORTRAN legacy code)		
1	0	0	-	Minute 1	Count 1.1	Count 2.1
2	2	2	-	Minute 2	Count 1.2	Count 2.2
3	4	4	-	Minute 3	Count 1.3	Count 2.3
(Etc.)						

6.8.2.3 Logged Data Files

The data from the sledge, such as depth, range off the bottom and distance covered are combined with positional data from the ship or from a Garmin GPS unit and fed into a pc, which logs the data to a file, and prints a hard copy for reference in case of data loss.

The data are logged in the following structure:

fl05001	-	Site ID Code
04/06/05	-	Date

195130, 0, 57.916, -0.502, 117.6, 0.98, 0

195140, 10, 57.917, -0.502, 117.7, 1.13, 1

195145, 15, 57.917, -0.502, 117.6, 1.15, 2

195150, 20, 57.917, -0.502, 117.6, 1.16, 3

195155, 25, 57.917, -0.502, 117.5, 1.18, 5

(Etc.)

cumulative time, run time, latitude, longitude, depth, height of rangefinder, distance covered.

In event of the failure of the rangefinder, odometer or "3 in 1", or when using the drop frame, additional code is used to generate distance from logged position or to simulate range data.

6.8.2.4 Work-up Code

The R code used to calculate densities is given as an Appendix 2, Working Document 5. This code has been annotated (text marked out with a hash) to explain the processes involved.

To summarize very briefly, the logged data and counts for each site are read in, the sledge parameters are then used to calculate an average width viewed for each minute of the run, and this is multiplied by the distance covered in each minute to give the area viewed. The burrow counts are then divided by the area to give a value for density.

This code also automatically generates diagnostic plots to identify any problems in the data which is being used. Figure 6.10 shows an example from the Inner Sound. The sledge begins to lift off the bottom around 4 minutes into the run, at which time burrow counts drop. As the range stabilizes, higher counts return.

6.8.2.5 Raising Procedures

An additional sequence of R code takes the output of the burrow density calculation routine and returns a vector giving the stratum to which each calculated density value belongs. Mean densities are calculated for each stratum, along with 95% confidence limits about this mean. Mean density, and the lower and upper density bounds, are raised to the total area or the relevant stratum, taken from the BGS sediment database. Abundances for all strata are then summed to give to give total abundance for the functional unit, which can be taken forward into the assessment process.

6.8.3 Cefas

To calculate the abundance estimate for the fishery, Cefas use the same method presented by FRS to ICES (Bailey N., 1993). For each stratum the abundance is calculated as a product of average density and the area of the stratum. The numbers are then summed to survey area. 95% confidence limits are calculated from the sum of the stratum variance.

6.8.4 IR -MI

The detail of the general raising methods for the Irish surveys are given in Annex 2 WD 2. Two approaches are used the empirical method for stratified sampling similar to Bailey *et.al.* (1993) and the geostatistical method which provides a krigged abundance and uncertainty estimates.

Two possible methods for estimating density at each station have been explored for WKNEPTV. The first involves obtaining 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 involves 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 each of these methods for the Aran UWTV 2006 survey are described in WD 2. These indicate a certain amount of variability at the minute-by-minute level but it is not too significant Also the minute-by-minute result corresponds extremely well with the mean for the whole station as in Figure 4 in WD2.

Data workup is currently through a series of excel spreadsheets but the intention is to move to an integrate framework linking the survey database to "R" based workup routines similar to those used by MARLAB. It is also hoped that the geostatistical analysis will be carried out in "R" rather than SURFER.

6.9 Integrated UWTV and trawl surveys

In addition to the standard approach of using UWTV surveys directly to estimate burrow density and abundance, UWTV technologies can be used to in conjunction with trawl surveys. Two approaches were discussed at the meeting. The first used UWTV surveys observations to standardized trawl catches these second uses a headline mounted camera to estimate catchability during a trawl survey.

In the Division VIIIab, IFREMER (France) has conducted a series of trawl surveys (EVHOE) directed to demersal fishes but these proved inadequate for *Nephrops*, either due to the trawl design or to the season (October-November, when females are less available). Moreover, these trawl operations did not take into account the diel variation of the emergency rate of *Nephrops*. A new series of trawl surveys targeting *Nephrops* started in the spring of 2006.

In July 2004, an UWTV survey was conducted on 6 sites of the great mud bank in Bay of Biscay, at depths ranging from 70 to 110 metres. Data from this survey (animal and burrow counts) were used to model the diel activity pattern of *Nephrops*. Although it would not be possible to regularly conduct UWTV surveys, existing results can be used to calibrate the trawl survey information taking into account changes in catchability.

In the Division IXa, IPIMAR (Portugal) will conduct a combined UWTV and trawl survey in June 2007. The depth range to be covered is 200–750 metres. At these depths, the usual UWTV surveys are impracticable, due to the length of the cable needed and its costs. The main advantage of combined surveys is the possibility of estimating both *Nephrops* abundance and catchability, particularly useful for calibrating trawl surveys.

In 2005, attaching an UWTV camera to the headrope of the trawlnet was tried. This technique has proven to be suitable for obtaining clear images of *Nephrops* and their burrows (Leotte and Silva, 2007 – Annex 2 WD 1), particularly because they occur at low densities and are clearly visible, even at a trawling speed of 2.8 knots.

The work gives a new opportunity to improve the abundance estimation for *Nephrops* using trawl surveys and WKNEPH recommends that these types of experiments/surveys to be continued.

6.10 Overall survey uncertainty

The factors contributing uncertainty to the survey output depend on the way the survey is used in the assessment or management advice process (Table 6.8). Using the survey as a relative burrow abundance index will be impacted on by variability, but any fixed systematic bias could be accounted for in the assessment or management process. If the index is simply used to observe trends in abundance, then any bias is of less concern than if used in an absolute sense. If the index is used to tune an assessment, then systematic bias would be factored into a catchability term.

To use the survey as an absolute abundance measure requires further knowledge to clarify various assumptions, particularly in relation to burrow occupancy. Many of the other contributions to uncertainty can be relatively easily addressed, and need to be taken into account to use surveys as an absolute abundance estimate. Burrow occupancy investigations would require dedicated observational and experimental effort, and given the potential contribution to the overall survey uncertainty, this should be given high priority.

The most uncertain application is using surveys to estimate absolute biomass. The main problem here is determining an appropriate size distribution to apply to the animal abundance estimate, to calculate biomass. There are also issues in how the size distribution of the animals generating the surveyed burrows relates to the size distribution of the overall population. Using the surveys as absolute estimates of biomass will have to take into account all the uncertainties identified in Table 6.8.

The harvest ratio process outlined in Section 7.2 uses the survey as an estimate of absolute abundance, and includes an additional assumption that the size distribution of the exploited population in recent years reflects future exploitation patterns. While the most appropriate use of the surveys is as a relative index of burrow abundance to tune an assessment, for many stocks the poor quality of catch data precludes this. Indeed, the uncertainties and bias in catch data are likely to be far greater than those for UWTV surveys for many stocks. Therefore, for many stocks the harvest ratio approach currently provides the best available basis for management advice.

Despite the uncertainties outlined, it should be remembered that uncertainty exists in all survey methods. In fact UWTV surveys are less likely to suffer from large interannual variations in abundance estimates and uncertainty compared with trawl or acoustic surveys. In addition, many of the identified uncertainties and accuracy problems can be addressed relatively easily with improved procedures, additional investigations and/or additional instrumentation.

Table 6.1. Variability in South Minch 2005 burrow densities (burrows/m^2) using fixed and variable heights in calculation of field of view.

	Mud	Sandy Mud	Muddy Sand
Variable Height	**0.68**	**0.54**	**0.37**
Fixed Height (0.88 m)	**0.69**	**0.54**	**0.39**

Table 6.2. Variability in South Minch 2005 population size and biomass using fixed and variable heights in calculation of field of view.

	Mud	Sandy Mud	Muddy Sand	Total
Variable Height	**206 m (4553 t)**	**1480 m (32692 t)**	**750 m (16572 t)**	**2436 m (53817 t)**
Fixed Height (0.88 m)	**209 m (4619 t)**	**1480 m (32692 t)**	**790 m (17468 t)**	**2479 m (54779 t)**

Table 6.3. Area viewed assuming different heights of the camera.

HEIGHT USED	CALCULATED VIEW AREA (M2)
10 minute average	**252.55**
1 minute average	**253.16**
Exact height	**255.89**
0.88 m fixed height	**202.78**

Table 6.4. Analysis of Variance table for effect of width of view and burrow density on proportional error of the density estimates from the first simulation.

Term	d.f.	Sum of squares	Mean square	*F*	Pr(*F*)
width	2	378.32	189.16	11454.77	<0.0001
density	1	0.0832	0.0832	5.04	<0.05
residual	44996	743.05	0.0165		

Table 6.5. Analysis of Variance table for effect of burrow diameter, density and width of view on proportional error of the density estimates from the second simulation.

	d.f.	Sum of squares	Mean square	*F*	Pr(*F*)
diameter	2	2190.302	1095.151	38215.37	<0.0001
density	3	0.242	0.081	2.82	<0.05
width	2	498.384	249.192	8695.57	<0.0001
diameter:width	4	28.459	7.115	248.27	<0.0001
residuals	35988	1031.32	0.029		

Table 6.6. Summary of burrow counts wholly within (A) and only partly within (B) the field of view. See text for further explanation.

Site	A	B	A+B	A+B/2	% difference
23	130	134	264	197	25
24	141	207	348	244.5	30
25	30	62	92	61	34
49	0	8	8	4	50
29	72	96	168	120	29
32	99	97	196	147.5	25
36	98	107	205	151.5	26
43	78	96	174	126	28
21	122	147	269	195.5	27
22	169	185	354	261.5	26
34	115	131	246	180.5	27
15	118	133	251	184.5	26
14	99	107	206	152.5	26
9	71	79	150	110.5	26
46	70	71	141	105.5	25
48	75	86	161	118	27
13	105	144	249	177	29
4	90	148	238	164	31
44	41	62	103	72	30
45	47	98	145	96	34
47	42	76	118	80	32

Table 6.7. Estimate of biomass in the Western Irish Sea based on commercial trawl data and survey data.

Mean weight commercial (g)	**15.8**
Mean weight surveys (g)	**10.3**
Biomass calculations	
Abundance =	**6 728 971 000**
mean wt commercial lengths (g)	**15.8**
mean wt survey lengths (g)	**10.3**
Biomass from commercial (t)	**106 107**
Biomass from surveys (t)	**69 548**

Table 6.8. Main perceived sources of uncertainty in UWTV surveys.

Use of survey	Source of uncertainty	Cause	Impact of uncertainty	Probable Magnitude	How addressed
Relative index of burrows abundance	Field of view	Variability in camera altitude and angle	Noise, but likely to overestimate	Variable but potentially moderate	Measurement of camera altitude or new laser scaling technology
	Length of tow	Uncertainty in tow track	Noise	Variable but low, depending on method	Measurement systems
	Burrow detection	Visibility	Probable underestimate	Variable	Formal acceptability criteria
		illumination and camera angle	Probable underestimate	Probably fixed within survey	Identify optimum and maintain consistency between systems
	Burrow identification	Confusion caused by other species	Noise, but likely to underestimate at high density, and overestimate in areas with high abunadance of other burrowers	Variable but likely to be low	Training
		Detection of burrow systems	Probably underestimate at high density	Moderate	Knowledge of burrow structure (resin casting and observation)
	Edge effects	Variability in burrow area, density and field of view	Overestimate	Moderate	Incorporate into workup and identify optiumum field of view
Absolute numbers	Burrow occupancy (100% assumed)	Empty burrows and multiple occupancy	Unknown	Moderate	Observation and experimental studies
	Area or boundary uncertainty	Differences between fished area, survey area and population area	Probable underestimate	Probably low, but area specific	Improved information on spatial distribution of population (survey coverage increased) and fishery
	Numbers outside survey area	Full population coverage lacking	Underestimate	Unknown, but area specific	As above
Absolute biomass	Size distribution of animals contributing to burrow estimate	Difficulties in population sampling related to burrow emergence	Unknown, but using trawl catch size distributions likely to overestimate (owing to emergence and selectivity issues)	Unknown, gear and area specific, but probably the largest uncertainty	Investigations into emergence, bias caused by gear selectivity and other approaches (e.g.. measuring burrows from still images, although this still includes uncertainty)
	Sex distribution as above	As above, length weight varies with sex	Noise	Probably low	Trawl data

USE OF SURVEY	SOURCE OF UNCERTAINTY	CAUSE	IMPACT OF UNCERTAINTY	PROBABLE MAGNITUDE	HOW ADDRESSED
	Additional biomass of animals not covered above	**Full population coverage lacking**	**Underestimate**	**Probably low**	**Observation and experimental studies**
	Biomass outside survey area	**Full population coverage lacking**	**Underestimate**	**Unknown**	**Improved information on spatial distribution of population (survey coverage increased) and fishery**

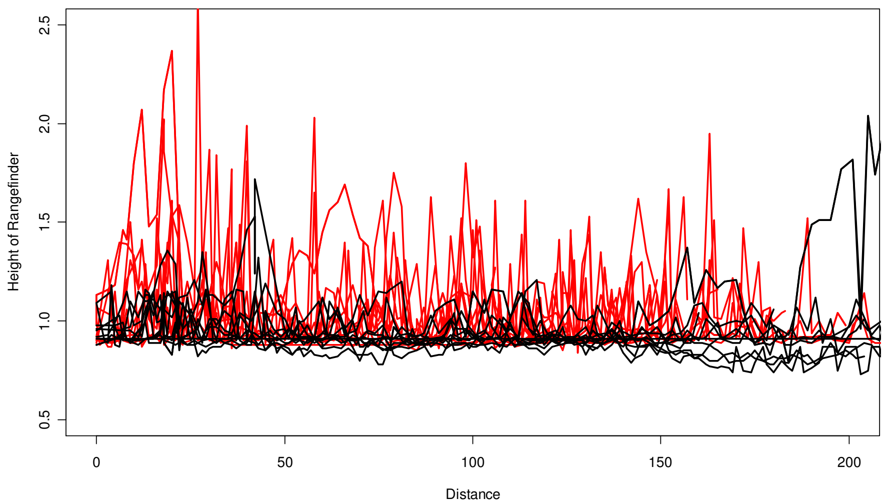

Figure 6.1. Height of the rangefinder recorded in ten 10 minute runs on the Fladen (red) and North Minch (black). The sledge sinks noticeably further into the soft sediments of the North Minch.

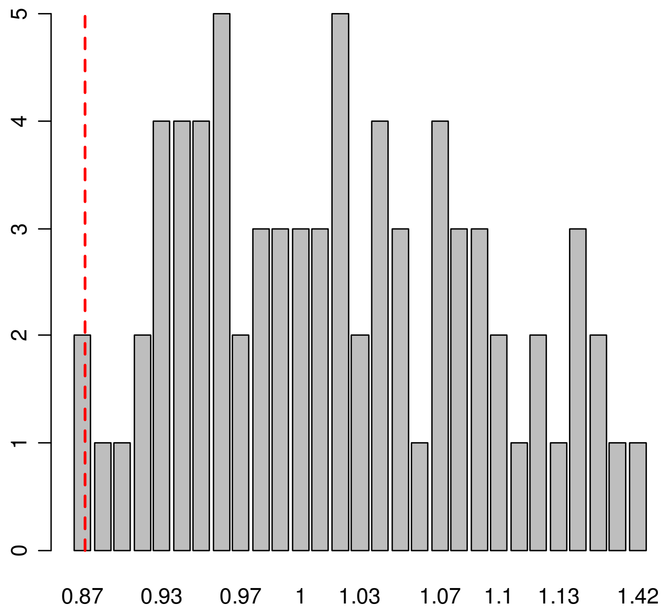

Figure 6.2. Distribution of mean rangefinder heights (m) on TV sledge runs in the Fladen, 2005.

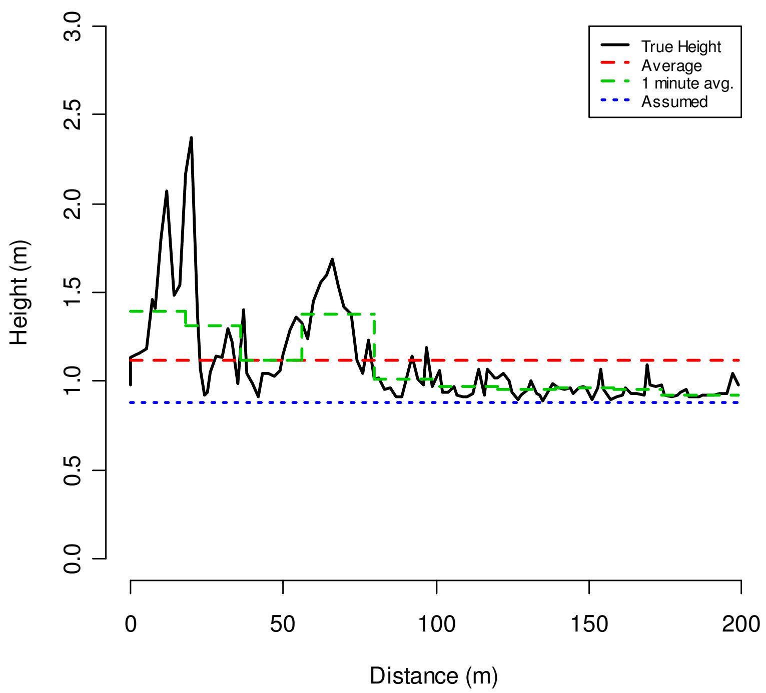

Figure 6.3. Range off the bottom during the course of a single run on Fladen, 2005.

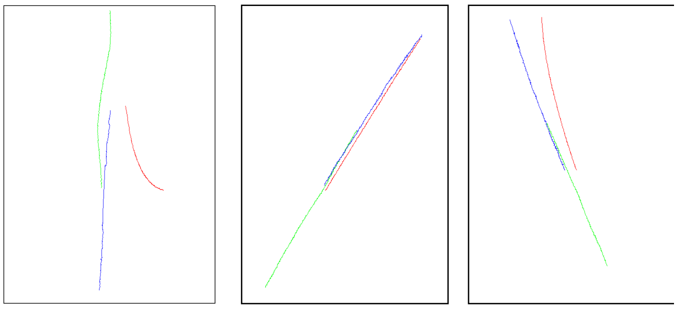

Figure 6.4. Behaviour analysis of the Ship (green line), USBL (blue line) and Layback (red line) tracks on UWTV Aran 2006.

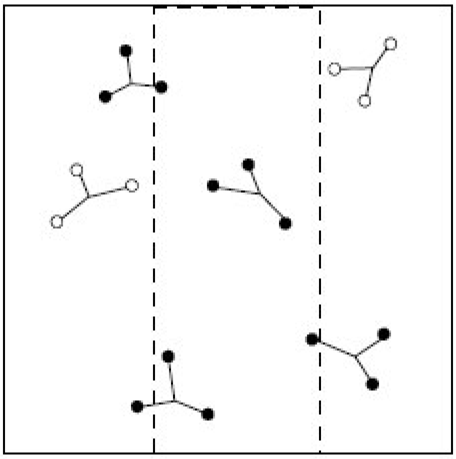

Figure 6.5. Pictorial simplification of the burrow counting methodology. The extent of the area of seabed viewed at a station is indicated by the dashed rectangle. Burrow systems with an opening within this area, which therefore would be counted, are indicated as solid circles. Burrow systems without an opening in the viewed area are indicated as hollow circles. Figure shows all burrows with three openings, but simulation allows number of openings to vary.

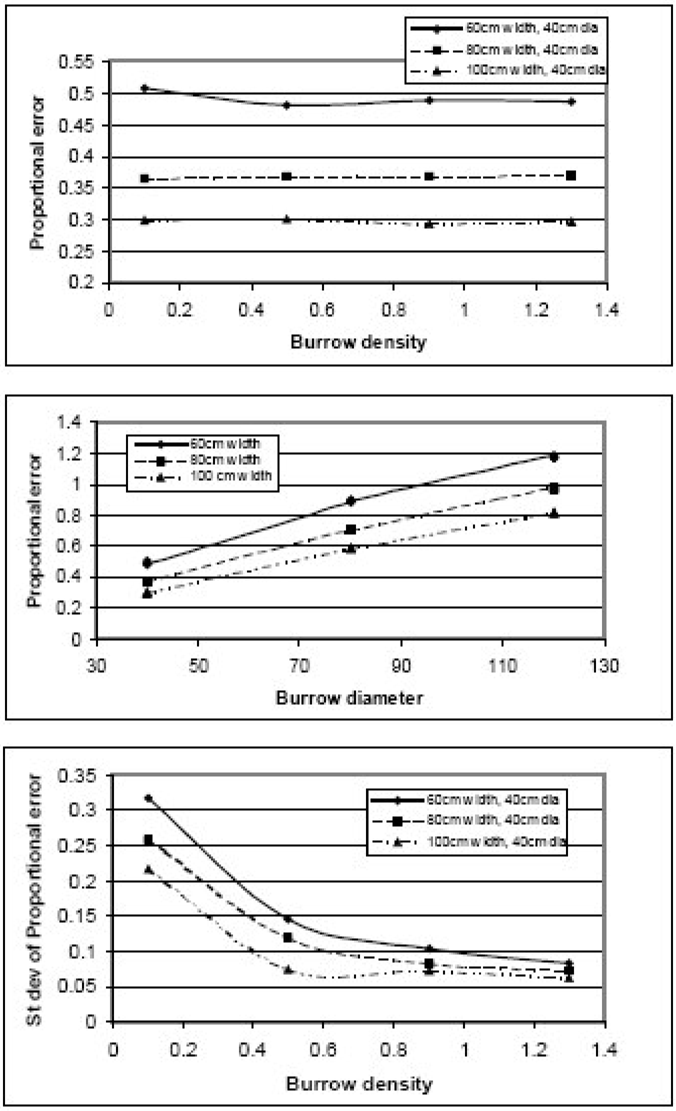

Figure 6.6. Plots of proportional error in relation to burrow density and burrow diameter, and standard deviation of proportional error in relation to burrow density, from the second simulation.

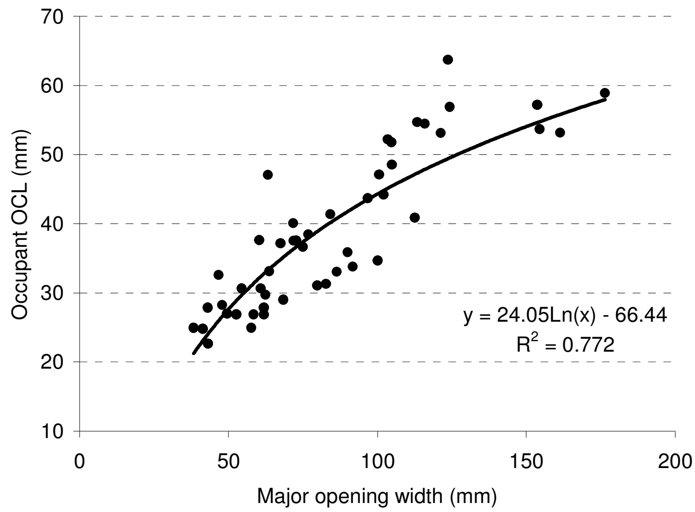

Figure 6.7. Estimated relationship between the width of a major burrow opening and the size of the occupying scampi (from photographs where animals were clearly associated with burrows) in SCI 1, New Zealand. Error in this regression is included in estimated length frequency distributions based on burrow sizes by bootstrapping.

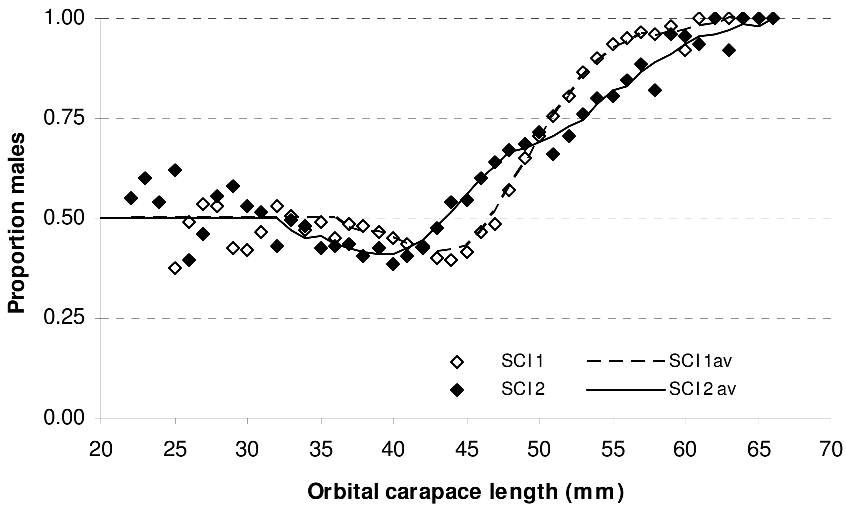

Figure 6.8. Proportion of males by size class averaged over all research trawl length frequency distributions in the modelled areas (areas calculated separately). The lines show a five-point moving average mean (35 mm OCL and above) used to provide a weighting for the estimation of mean individual weight from animal and burrow sizes measured from photographs.

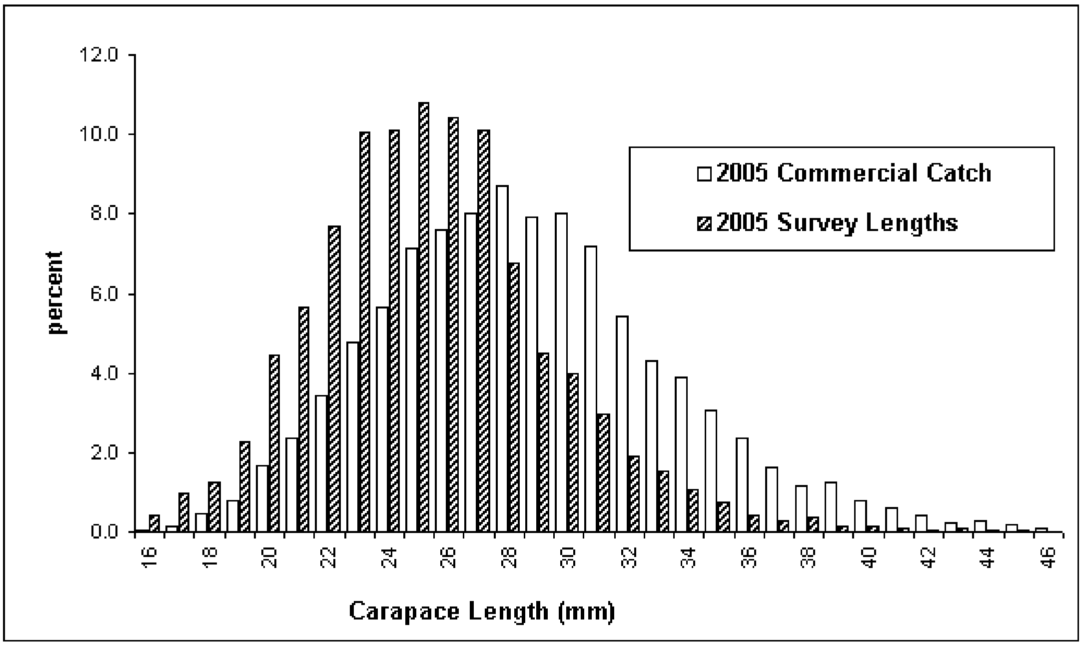

Figure 6.9. Carapace length frequency distribution of survey caught and commercially caught *Nephrops*.

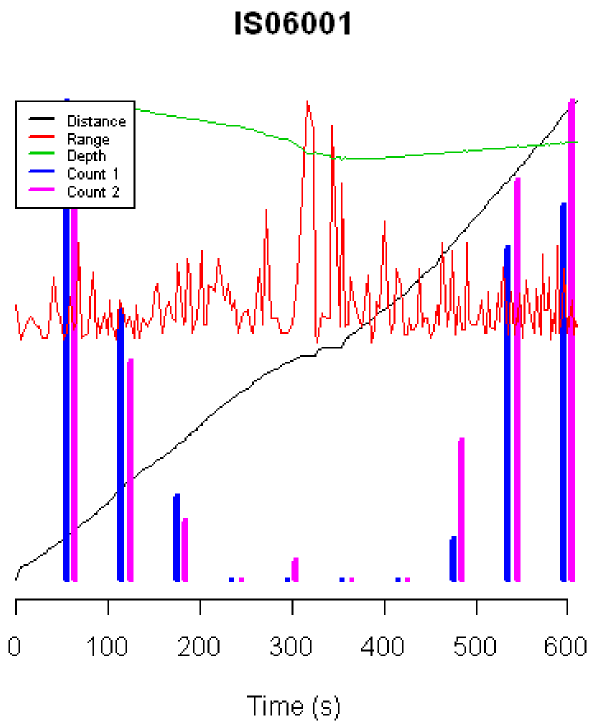

Figure 6.10. Diagnostic plot produced by R burrow density calculation routine to check the integrity of input data.

7 Using surveys in assessment and provision of management advice

7.1 Review of progress to date

7.1.1 North Sea and West of Scotland stocks

TV survey abundance data were first used in the provision of catch advice for the Fladen (FU 7) *Nephrops* stock in 1998 (ICES, 1998). The fishery at the Fladen developed relatively rapidly during the late 1980s and 1990s and as a consequence only a rather limited amount of commercial data were available for stock assessment purposes at this time. TV surveys, which began at the Fladen in the early 1990s, indicated that the stock was relatively stable and it was felt that there was potential for an increase to the very low TAC. The TV survey estimates of stock abundance in numbers (averaged over a 3-year period) were used to estimate a potential landings level based on a 'harvest ratio' defined as the ratio of total catch in numbers to stock abundance in numbers. For the Fladen, an arbitrary conservative harvest ratio of 7.5% was initially chosen which was at the lower end of harvest rates experienced by the stocks around Scotland at that time (ICES, 1998). The resulting total catch in numbers was then translated into a biomass by distributing the numbers according to the observed length-frequency distribution of the recent catch (3 year average from market sampling and discard data with 75% discard mortality) and applying an appropriate length-weight relationship. The landed portion of this biomass was then used to provide TAC advice.

Historically, the other *Nephrops* stocks to the West of Scotland (North Minch FU 11, South Minch FU 12, Clyde FU 13) and in the North Sea (Farn Deeps FU 6, Firth of Forth FU 8, Moray Firth FU 9) have been assessed by slicing the length composition data into age groups (based on von Bertalanffy growth curve derived 'slicing points') and making used of catch-at-age based assessment methods. However, in 2005, both ICES assessment WGs dealing with these stocks (WGNSDS and WGNSSK) decided that as a result of poor quality landings data and concerns that underlying model assumptions may be violated by some of the unusual features of *Nephrops* biology, the analytic catch-based assessments should be discontinued (ICES, 2006a and 2006b). Based on the trends in TV survey abundances and additional indicators of stock condition such as mean size, ICES concluded (ICES, 2005 and 2006e) that these stocks appeared to be exploited at sustainable levels and that effort levels should not be allowed to increase. Survey data for stocks to the West of Scotland indicate increasing abundance while those in the North Sea appear to be fluctuating without trend.

Providing TAC advice based on the TV survey abundance estimates and a harvest ratio for these stocks (other than Fladen) has proved problematic. A number of alternative approaches to deriving a suitable harvest ratio were considered and it was eventually agreed (STECF, 2005) that a rate consistent with fishing at a sustainable fishing mortality ($F_{0.1}$ from a combined sex length cohort analysis YPR curve) was most appropriate (see Section 7.2 for further discussion). For most stocks considered this equated to a harvest ratio of approximately 20% (STECF, 2005). A more conservative harvest ratio (10%) was advised for the Fladen due to: the relatively recent nature of the fishery, the limited background biological and fishery data and the fact that the density is very much lower, with the large abundance estimate being derived from the large ground area. Landings were estimated for each functional unit using the method originally applied in the Fladen (see above), then summed to provide TAC proposals for each management unit. Additional landings (based on average reported landings) were added to the totals to account for functional units or areas with fisheries but with no TV survey (STECF, 2006). This resulted in a TAC of 26 144 t for N Sea (IIa and IV) in 2007 (a reduction of 7% on 2006) and 19 885 t for West of Scotland (a 13% increase on 2006).

7.1.2 Irish Sea

Background

The method used to assess Irish Sea *Nephrops* is based on the approach developed in Scotland (Section 7.1.1) with modifications necessitated by local conditions and equipment availability. The western Irish Sea area of mud (FU15) is surveyed using a systematic grid approach with a spatial offset applied each year. This contrasts with the stratified random approach used in Scotland. Two vessels participate in the survey employing identical equipment and protocols on each. Between 144 -166 stations are surveyed using a 10 minute sledge run at each. Distance travelled was estimated from ship's navigation with a fixed width field of view assumed whereas in Scotland an odometer and rangefinder monitor track dimensions directly. The final work-up stages were the same as in Scotland. Detailed counts were made in the laboratory and abundance estimates for the overall area surveyed by UWTV raised to the overall area of the mud (determined by reference to geological charts, direct observation and industry input). Commercial fishery data provided length compositions used in the derivation of a harvestable amount with an adjustment for discards based on ROI observer data.

Survey indices and estimates of abundance

The approach for calculating landings potential from TV surveys has been to use an average abundance index calculated over three years (ICES 1998 and ICES 1999). This, however, was developed for stocks where other population indicators were relatively static and the time-series of TV estimates was relatively long. For FU15 it was considered inappropriate to use three years because of the short time-series and because of the apparent decline in stock size suggested by UWTV surveys. For this reason harvest options was provided using a point estimate from the 2005 TV survey. The total burrow count for FU15 in the 2005 survey was calculated as the mean density for non-zero stations multiplied by the estimated survey area of 5790 km^2. Zero stations were typically at or beyond the boundary drawn for calculating the survey area. The method established for West-of-Scotland (VIa) and North Sea (IV) stocks for estimating abundance was adopted for FU15. This method consists of multiplying the number of burrow clusters by the harvest rate to give a figure of total numbers removed by the fishery (adjusted for discard survival). The numbers are then partitioned between landings and discards and landed numbers multiplied by the expected mean weight of landed *Nephrops*.

The $F_{0.1}$ catch for FU15 was calculated using the same method to that described for stocks in areas VIa and IV (See Section 7.2). The $F_{0.1}$ harvest rate of 20% that was adopted for those stocks was also applied to FU15.

The 2005 index of abundance (75 Kg/nm) from AFBI annual trawl surveys was within the 95% confidence interval (47 to 77 Kg/nm) of the mean of the time-series over the period 1994 to 2004. The development of stock abundance in future years was not clear, but given the available evidence, the 2005 UWTV abundance estimate provided an appropriate value for use in projections.

A harvest rate of 20% ($F_{0.1}$) was applied and length frequencies for male and female landings and discards were the means of the data for the international fishery in 2003–2005 and were raised to the $F_{0.1}$ landings of 16 748 t. A 75% discard mortality was assumed as in Scottish studies.

Management considerations

Nephrops in Subarea VII are broken down into 3 management areas (MA) and 7 functional units. MA J (FU 14 and 15), MA L (FU 16 - 19) and MA M (FU 20 - 22). An annual TAC applies to the whole of Subarea VII and the landings estimate for 2007 from FU15, assuming a 20% harvest rate and biomass based on the 2005 estimate was 16 748 t. The management of area L and M allocation remained constant at the 2003 levels of 3300 and 4600 t respectively and FU14 remained at 500 t which provided a TAC for Subarea VII in 2007 of 25 148 t This was an approximate 17% increase on the TAC for 2006 (21 498 t).

7.1.3 Aran Grounds

The growing time-series of survey data for the Aran grounds was considered in the stock assessment process by WGHMM for the first time in 2006. Compared with other stocks the time-series of fishery dependent data on size distributions, catch and effort is relatively short precluding a full analytical assessment. The WG explored harvest ratio options using the LCA approach previously used by WGNSDS and WGNSSK. A number of annual LCAs were carried out for each year and each sex. A summary of the results and the equivalent landings estimate using mean size from the commercial data is given in Table 7.1. The results of the LCA target reference point $F_{0.1}$ translate to landings advice of between 2–4kt. This is significantly higher than the average annual reported landings figure of ~800 t. The WG raised concerns about the appropriateness of the LCA assumptions, the mean size assumption and the accuracy of the landings statistics. The WG considered that it would be premature to base any management advice directly on this short series (4 years) which is due to be augmented further in June 2006.

At ACFM the survey was considered in the state of the stock section:

A recent UWTV survey series shows increased burrow density and estimated biomass from 2002–2004 before declining slightly in 2005. For this stock there was no evidence of stock decline and the management advice was that effort should be constrained to recent levels at an appropriate geographical scale (FU).

Prior to the 2006 survey the fishing industry raised concerns about the state of the stock indicating that catches over the winter and early spring were lower than normal. The 2006 survey shows a large decline (-40%) in burrow abundance. An investigation of the relationship between the survey density estimates and the monthly landings was carried out in WD 2 to see if the survey might have any predictive power for future landings. Figure 7.1 summarizes a similar investigation for lpue. The fishery can be broken into two seasonal components March-June and October-November. The spring fishery is comprised of both sexes whereas the autumn fishery is mainly (>80%) males.

The analysis indicates that landings in the autumn fishery are negatively correlated with the survey abundance index while the spring fishery is positively correlated with survey abundance (although the correlation was not as good and based on only four points). Various biological explanations might explain this: large abundances of small animals may reduce the emergence of males in the autumn and by the following spring the large numbers of newly burrowing animals are contributing to the landings. This analysis should be carried out on lpue rather than landings but that data were not available at the meeting and concerns about the accuracy of the landings data persist. The main conclusion is that the relationship between burrow abundance and landings is likely to be complex. Seasonal and growth related considerations should also be taken into account for further investigations.

7.2 The harvest ratio approach

Background

A number of approaches have been suggested for the derivation of harvest ratios appropriate for *Nephrops* stocks. When this method was first developed (for the Fladen) in 1998 (ICES, 1998) an arbitrary conservative rate of 7.5% of the TV abundance averaged over the previous 3 years was chosen to calculate a suitable TAC. This was at the lower end of harvest rates observed for a range of other *Nephrops* stocks (as calculated at the 1998 *Nephrops* Study Group: ICES 1998) and therefore thought to be a relatively cautious value.

The harvest ratio was applied to total TV abundance in numbers to calculate a total number of removals. These are then translated into a biomass by distributing according to the observed length-frequency distribution of the recent catch (3 year average from market sampling and discard data with 75% discard mortality) and applying an appropriate length-weight relationship. The landed portion of this biomass was then used to provide TAC advice. This translation of removal numbers to TAC makes the assumption that the size distribution of catches in the TAC year is the same as that in recent years.

In trying to apply this method to more heavily exploited stocks, an alternative method for developing appropriate harvest ratios has been needed. Two main approaches to deriving harvest ratios for particular stocks have been considered by ICES in recent years (e.g. ICES 2006c, 2006e):

- the ratio of landings and TV survey abundance biomass averaged over some historical period
- a ratio which is consistent with fishing at a sustainable rate.

Given the known reporting problems for many of these stocks, it is expected that a harvest ratio derived from the ratio of reported landings to TV survey abundance is likely to be a substantial underestimate of the actual harvest rate that has been sustained by a particular stock. Additionally, for lightly exploited stocks the resulting harvest ratio is likely to be very low and gives no indication about potential sustainable harvest ratios.

As a consequence, the autumn 2005 meeting of STECF (STECF, 2005) was asked to 'identify which harvest rates for stocks of *Nephrops* are consistent with exploiting the stocks at maximum sustainable yields (or suitable proxy)….'. The approach of STECF was to examine a yield-per-recruit (YPR) curve approach which had previously been presented at WGNSDS (ICES, 2006b). The single sex YPR curves were calculated from a LCA (Jones, 1979; Jones, 1984) then summed to obtain a combined sex curve. The combined sex fishing mortality (F on the x-axis of the YPR curve) was calculated as the mean F_{bar} (males and females) weighted by number of individuals of each sex caught at the current level of exploitation according to the LCA. It was advised by STECF that a relatively cautious reference point such as $F_{0.1}$ should be used to provide an indication of an appropriate harvest rate. $F_{0.1}$ has been used successfully as a management reference point for Icelandic *Nephrops* stocks and as a reference fishing mortality in New Zealand for both cockles (Morrison and Cryer, 1999) and scallops (Cryer, 1998). Estimates of $F_{0.1}$ as an instantaneous mortality rate were converted to equivalent removal percentages and used as a first approximation of a harvest rate. These turned out to be about 20% for each stock considered.

Alternative derivation of harvest ratios

A number of potential weaknesses with this LCA based approach relating to the simplicity of the model and its inherent assumptions were highlighted by WKNEPH (ICES, 2006 d). In particular, there was concern about whether the combined sex yield-per-recruit had appropriately accounted for the likely different exploitation rates of males and females. It was therefore felt that additional simulation work and testing of the robustness of $F_{0.1}$ was required.

A working document was presented to the 2006 meeting of WGNSSK (Dobby and Bailey, 2006) which derived YPR curves using a simulation approach with various assumed exploitation patterns rather than LCA derived exploitation rates. This approach meant that the derived curves were not dependent on commercial length frequency data (obtained from stocks with likely misreporting) and also that the sensitivity of the results to different assumptions about exploitation patterns could be easily explored. The calculations were carried out using a seasonal age-based simulation model in which males and females (and mature and immature individuals) are modelled separately. The model is therefore able to account for differences in the way the male and female populations are exploited due to different seasonal burrow emergence behaviour and seasonality in the fishery.

A more elaborate simulation model which incorporates a length-dependent selectivity function is described in a Annex 2 WD (WD 6) to this Workshop. Mean length-at-age (quarterly) is calculated from appropriate von Bertalanffy growth parameters and then fishing mortality-at-age calculated from the length dependent selectivity curve. For a particular set of sex, age and quarter dependent fishing mortalities, equilibrium yields were calculated for males and females separately, then summed to calculate a total yield and hence yield-per-recruit curves. Harvest ratios (at a particular fishing mortality multiplier e.g. $F_{0.1}$) are calculated as the total number of individuals caught divided by the total number of individuals in the population (for sexes separately and combined). Population abundance was calculated over a variety of age ranges (2–15, 3–15) and in different quarters to mimic alternative possible survey "catchabilities" and timings.

In summary, the results of investigations carried out here show that:

- a particular combined sex harvest rate can imply quite different sex-specific fishing mortalities and harvest rates depending on relative burrow emergence of males and females and seasonality of the fisheries.
- total harvest ratios equivalent to fishing at $F_{0.1}$ ranged from under 10% to about 25% with the lowest ratios occurring in scenarios with much reduced mature female catchability.
- a combined sex harvest rate of 20% was achieved by fishing at a sustainable level between $F_{0.1}$ and F_{max} for the combined population.
- harvest ratios resulting from fishing at $F_{0.1}$ for slow growing stocks were found to be lower than those for faster growing stocks, although in all cases, only by a few per cent.

Although the investigations carried out here appear to conclude that a 20% harvest ratio is sustainable, a number of outstanding issues need to be highlighted. In the simulations presented in WD 6, all calculations of harvest ratio are total catch (all ages) relative to total numbers aged either 2+ or 3+ (i.e. the burrows of age 1 animals are not visible or have zero "catchability" for a TV survey). Clearly if the TV abundance is representative of all individuals in the population (rather than just the exploitable component) then a harvest rate of 20% (in numbers) would imply fishing at a somewhat higher rate, and possibly above F_{max}.

Additionally, there remains further scope for incorporating more biological realism into the population model (such as variable male catchability, variable growth) and further examining the sensitivity to model assumptions.

Non-equilibrium simulations

The above calculations of harvest ratio and $F_{0.1}$ are all based on YPR curves and therefore are applicable to stocks in equilibrium. However, it is unlikely that the *Nephrops* stocks to which the approach has been applied are actually in equilibrium due to variable recruitment. Some very simple simulations in which a fixed harvest ratio was applied to a stock with variable recruitment have also been carried out. The age-structured model was parameterised to be consistent with a typical Scottish *Nephrops* stock: using Firth of Forth growth parameters, assuming reduced female catchability over winter and an appropriate length-dependent selectivity function. The stock was initially assumed to be in equilibrium with fixed recruitment and fishing mortality. Recruitment is then generated from a normal distribution with arbitrarily chosen CV. The harvest ratio of 20% was applied to the abundance in Q3 numbers summed over ages 3–15+ averaged over the 3 most recent years (excluding the current year). Abundance is calculated at the start of quarter 3 to be consistent with the timing of the Scottish TV surveys. The TAC for the current year+1 is then calculated from the harvest rate removals and the average catch-at-age composition from the previous 3 years. The model then calculates the fishing mortality multiplier required in the current year+1 to exactly take the calculated TAC for that year given the random recruitments that have occurred.

Clearly the application of a TAC calculated as 20% harvest ratio of 3-year mean TV abundance does not actually result in a harvest ratio of 20% when taken in current year+1 as population abundance will have changed due to recruitment and mortality in the intermediate year (current year). However, the fishing mortality multipliers required to take the TAC in current year+1 show only small variations away from $F_{0.1}$ in the simulations carried out here.

The exploratory simulations presented here all assume perfect information, exact implementation of the 20% harvest ratio derived TAC and no discarding. A further step would be to evaluate the robustness of the approach to: errors in implementation, variable discarding, and uncertainty about the age range of the stock represented in the TV abundance.

A further outstanding issue associated with the harvest ratio approach includes the problem of converting harvest ratio based on TV abundance numbers into a TAC biomass. The approach adopted to date converts harvest rate removals in numbers into a potential TAC biomass using commercial length frequency data. This makes the assumption that future catch-at-length (or age) composition is the same as the recent historical catch. An alternative option would be to convert TV abundance numbers into biomass and then apply a harvest ratio to the biomass to obtain an appropriate TAC. The difficulty then, however, is converting TV survey numbers into a biomass when the actual size distribution of the burrow forming individuals is unknown. See Section 6.7.3 for further discussion.

7.3 Potential for using surveys for calibration of assessments

ICES area

Many of the stocks in the ICES area for which TV surveys are currently undertaken have rather uncertain reported landings or only a short time-series of commercial data. At present, there is therefore little scope for using TV surveys as fishery-independent calibration indices in catch-based stock assessments. However, this does not preclude the use of such an approach in the future should reliable time-series of catch data become available. Possible methods (which all require growth information) include the use of a total abundance index in a catch-at-age based assessment (e.g. using ICA) or as a size structured index in a length-based assessment (e.g. New Zealand application below). The use of such typical assessment models, however, would be accompanied by the usual caveats concerning the use of models making dynamic pool assumptions for sedentary stocks (ICES, 2006 d).

NZ-NWIA

NIWA is developing a Bayesian, length based model for *Metanephrops challengeri* in New Zealand, implemented in the CASAL (**C**++ **A**lgorithmic **S**tock **A**ssessment **L**aboratory) software suite. This model (presented to the ICES WGNEPH in 2004: ICES 2004) was initially developed for one stock (Cryer *et.al.*, 2005), but has now been further developed and extended to a second fishery (Tuck and Dunn, 2006). Full details of the model structure are provided in Tuck and Dunn, 2006.

An entirely length-based model approach has been chosen, based on growth transition matrices, and the model includes commercial cpue and catch-at-length, multiple fishery-independent trawl surveys, tag- and aquarium-based growth studies and a series of quantitative photographic surveys. These surveys have been used in the model as both a relative abundance index and a biomass index (in different runs). A length-frequency distribution of the surveyed population is estimated from burrow sizes (for both approaches), and for survey use as a biomass index, biomass is estimated from this length distribution and length specific sex ratio information (see Section 6.7).

For both approaches, the survey index is related to the modelled population with a *q-Photo* (catchability) term. This *q-Photo* term is interpreted as the proportion of model stock abundance (or biomass) explained by the burrows included in the analysis of photographic surveys (assuming 100% occupancy). Cryer *et.al.* (2005) assumed a lognormally distributed prior on *q-Photo* of 1.0, and tested c.v.s of 0.4, and 0.8 (with little obvious effect on the behaviour of the model). Following discussions within the NZ Ministry of Fisheries Shellfish Fisheries Assessment Working Group (SFAWG), more recent model developments (Tuck and Dunn, 2006) have used an alternate approach to estimating *q-Photo*, derived from the factors thought to contribute photo survey “catchability”, using the approach of Cordue (2001).

Estimation of *q-Photo*

The factors considered to affect *q-Photo* (when interpreted as the proportion of model stock abundance explained by the burrows included in the analysis of photographic surveys) are:

- Spatial coverage of the survey compared to modelled area
- Major burrow opening occupancy rate
- Major burrow opening detection rate

with the three factor being multiplicative. It is currently assumed that *q-Photo* is constant over time and between strata and stocks, although differences in underwater visibility and the occurrence of other burrowing species are likely to have an influence on detection. Two approaches have been considered, (1) assuming that the probability distribution of each of the factors is uniform and (2), using the mean occupancy and detection rates estimated for *Nephrops* and video surveys, along with the assumed bounds to estimate beta (since the distribution is bounded between 0 and 1) and gamma distributions for occupancy and detection, respectively. A further approach recently suggested by the SFAWG but not yet investigated is simply to define a mean and upper and lower bounds for each factor, generate an overall mean and upper and lower bounds, and then fit a lognormal distribution to these limits. SFAWG also suggested it may be possible to split the detection factor into burrow identification and burrow visibility components. While in approach 1, the assumption of uniform factor distributions is perhaps unlikely (intermediate levels of occupancy and detection seem more likely than the extremes), approach 2 may put too much weight on data collected for a different (although similar) species, and a different survey approach (video counting of burrow systems rather than still photography counting of major entrances).

Spatial coverage determines a raising factor for converting the survey estimate to the modelled area estimate. The modelled area is defined by the survey strata, and therefore spatial coverage can be assumed to be 100%.

Burrow occupancy rate relates the numbers of burrows to the numbers of scampi in the survey area. Photo surveys for scampi in New Zealand are based on counts of major burrow openings. Although more than one scampi may inhabit a burrow system (as observed for *Nephrops*; Bell *et.al.*, 2006), it is assumed that each individual would have its own major opening, and maximum occupancy is 1. Over a whole survey the bounds on occupancy rate are assumed to be 0.1 to 0.9. No studies to date have estimated scampi burrow occupancy in New Zealand. Marrs *et.al.*, (1996) analysed datasets from seven field programmes (from SCUBA diveable depth on the west coast of Scotland) and estimated burrow system occupancy to be 68%.

The burrow detection rate relates the numbers of burrows counted to the numbers of burrows present on the seabed. No studies to date have estimated scampi burrow detection rate in New Zealand. However, comparison of the canonical indices from individual readers in the analysis of reader bias (Tuck *et.al.*, 2006 and see QA section) may provide an initial indication of the range of detection rates (comparing the least and most conservative readers). If it is assumed the most optimistic reader had a detection rate of 1 (100%), then the least optimistic would have a rate of 0.28 (only detecting 28% of burrows). If the least optimistic reader had a rate of 1 then the most optimistic reader would have a rate of 3.55 (estimating 3.55 times more burrows than actually present). At an individual image level detection rate may be zero, but the bounds on detection rate over a whole survey are assumed to be 0.1 to 3.55. Marrs *et.al.*, (1996) compared *Nephrops* burrow system counts from video survey tows and diver, and found that estimates were not significantly different for experienced readers in relatively "simple" burrow communities, but that detection rates from video (video count / diver count) were 1.5 (counts overestimated by 50%) where other burrowing species made detection more complex.

The overall estimates of the prior distribution for *q-Photo* were obtained by sampling at random from the factor distributions (for approach 1) or (for approach 2) and combining values multiplicatively (Figure 7.3). This process was repeated 10 000 times. The resulting distributions were both approximately lognormal (although more so for approach 2) with mean and standard deviation (of loge q) of -0.461 and 0.972 (Figure 7.3) for approach 1 (uniform factors), and -0.060 and 0.468 (Figure 7.4) for approach 2 (more informed factors). The poorer fit to the lognormal distribution of the q-Photo estimation in approach 1 may have lead to an underestimation of the mean and an overestimation of the standard deviation in the approximation (Figure 7.3).

7.4 Surveys as tools in management process

The utility of surveys in the management process is often constrained by the management that is in place. Management measures and processes differ greatly between European regions and within the EU. These include variations in MLS, bycatch limitations, gear design specifications and the compulsory use of selectivity devices. Management of many demersal fish and *Nephrops* stocks is primarily by TACs and quotas (excluding the Mediterranean) and an array of technical measures arising from both EU and national legislation. Regular annual UWTV surveys in the UK and Ireland have been developed to provide annual stock indicators (or assessment tuning indices) that can be used in the formulation of management advice for this type of annual TAC or effort management regime. Management of Mediterranean resources is based on capacity measures (rather than on catch limits and control of bycatch and discards) and technical measures concerning mostly gear specifications and spatio-temporal restrictions or closures.

New UWTV surveys may provide useful information for “alternative management approaches” e.g. closed areas, seasons, or fishing times. For stocks which are subject to recovery plans (e.g. Cantabrian Sea and Western Galicia, EC No 2166/2005), UWTV surveys may also be useful for providing information on pulses of recruitment which may be an early indication of stock recovery.

At present there is no legal binding requirement for stock assessment of *Nephrops* stocks (although the new Data Collection Regulation (for 2008) is expected to increase data collection for priority species including *Nephrops* stocks by applying the métier/fleet-fishery based approach to sampling). Currently, over 30 *Nephrops* stocks are assessed regularly by ICES in the N. E. Atlantic as opposed to 1–2 stocks in the Mediterranean which are assessed less frequently (once or twice in the last 10 years by GFCM-SCSA). Historical fishery data collection for assessment also differs widely. In the Mediterranean regular data collection is rather recent and sparse. The harmonized collection of fisheries, biological and economic data, arising from the EU 1543/2000 and 1639/2001 regulations, has been implemented in 2002. The annual MEDITS trawl surveys (similar to IBTS) (Bertrand et.al. 2002) began in 1994 with first surveys conducted along the coasts of 4 EU MS (Spain, France, Italy and Greece) with further additions in 1996 and 2000 (Adriatic Sea, S. Alboran Sea, contributions from Malta and Morocco). As with the few earlier *Nephrops* stock assessments, future assessments in the Mediterranean will probably be based on commercial data and/or MEDITS data (1 summer survey/year). The shortcomings of using trawl data, without input from UWTV surveys, are discussed in previous sections of this report.

Developing annual surveys may not be a realistic prospect in the Mediterranean but occasional or experimental surveys could be used to advise on spatio-temporal closures if this was considered an appropriate management tool. The method was very recently presented at the SCSA of the GFCM (GFCM 2006; Morello *et.al.*, 2006) with the aim to investigate the possibility of using UWTV surveys to assess the *Nephrops* stocks in the Adriatic Sea.

In all areas there are an increasing number of policy initiatives and International conventions towards the protection of the marine environment, halting biodiversity loss, reducing discards and the implementation of the Ecosystem approach to fisheries. Although a number of *Nephrops* fisheries are or being developed as single species (through gear shifts or advances in selectivity) many of EU *Nephrops* fisheries are essentially multispecies fisheries. Surveys may be useful to inform new management measures. For example it may be possible to use UWTV surveys to identify periods of peak emergence and this could feed into responsible fishing practices e.g. by only fishing during periods of peak emergence cutting down on a number of ecosystem impacts.

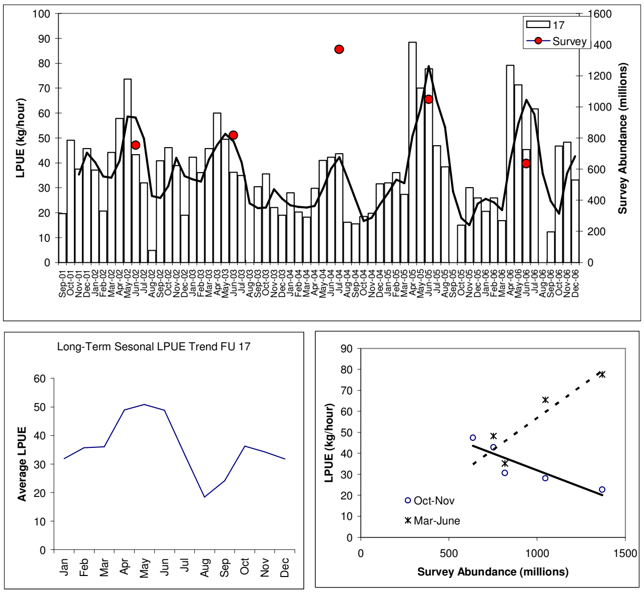

Figure 7.1. a) The monthly lpue from FU 17 and survey abundance index b) mean standardized long term (1995–2006) seasonal trend in lpue for FU 17 and c) the relationship between landings for two periods and survey abundance estimates.

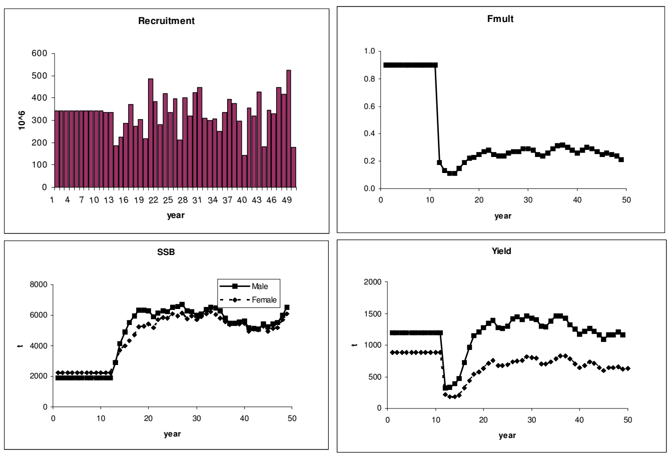

Figure 7.2. Single realisation of 20% harvest ratio (of 3+ population numbers) derived TAC with variable recruitment (CV=0.3). Effort distributed evenly across year and reduced mature female catchability in Q1 and Q4.

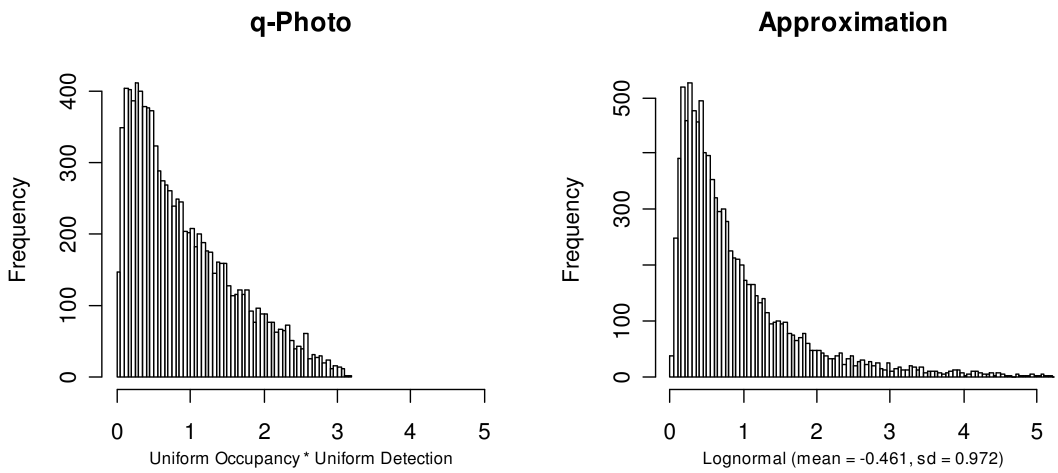

Figure 7.3. Estimated prior for *q-Photo* from uniform factors (left panel), and distribution derived by random sampling from a lognormal distribution with estimated lognormal parameters (right panel).

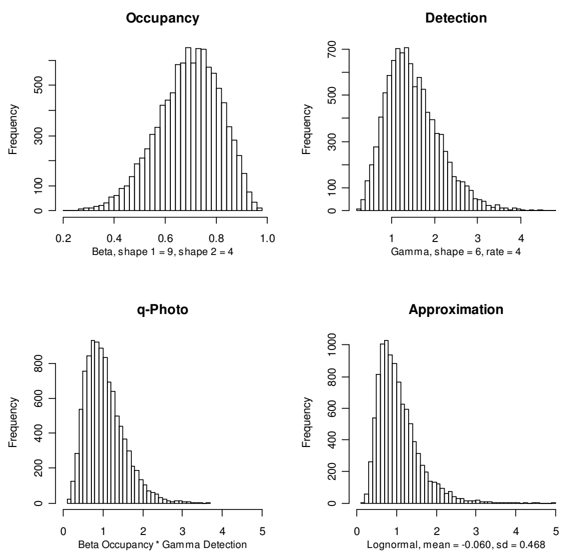

Figure 7.4. Estimated distributions for burrow occupancy and detection, prior for q-Photo multiplicatively from these factor distributions, and distribution derived by random sampling from a lognormal distribution with estimated lognormal parameters.

Table 7.1. A summary of the LCA reference fishing mortality points, equivalent harvest ratio and estimated landings equivalents for the Aran Grounds.

	Fishing Mortality	Approximate harvest ratio	Landings based of average survey 02-05
Average $F_{0.1}$ Males	0.26	23%	4,041
Average $F_{0.1}$ Females	0.12	11%	2,039
Average F_{bar} Males	0.57	43%	8,137
Average F_{bar} Females	0.31	27%	4,336

Table 7.2. Estimated bounds on factors influencing *q-Photo*. The distribution of each of the factors was assumed to be uniform between the bounds. See text for details.

FACTOR	LOWER BOUND	UPPER BOUND
Spatial coverage	**1**	**1**
Occupancy rate	**0.1**	**0.9**
Detection rate	**0.1**	**3.55**
Product (overall bounds)	**0.1**	**3.195**

8 The utility of surveys for habitat and ecosystem assessment

Transects with towed imaging instruments are a valuable alternative to traditional –destructive – sampling. They reveal structures and aspects of the seafloor that cannot be achieved with other methods and in a comparable short time (Rumohr, 1996). Video imaging allow not only the depiction of the sedimentary habitat in its undisturbed condition but may also document the distribution and abundance of features (biological or non-biological), associations between species and their behaviour, types of habitat, spatial changes in and between habitats and temporal changes over different time scales. The application of tow sledges (and other imaging systems) has been extensively reviewed in Solan *et.al.* (2003). For example, video surveys have revealed the disturbing effects of fishing activities on surface fauna and of the structures they produce. Burrows are flattened, tracks are wiped out and fragile feeding structures are destroyed. With calibrated views and known tracking, trawling impacts have been semi-quantified and area maps produced with density plots of trawling impact (Coggan *et.al.* 2001).

There is a long history of profiling exercises with video, photo, and sounding sensors that helped for a better habitat description of the sedimentary habitats and gave alternative instruments for a state of the ecosystem assessment. Also the use of headline cameras helped to bridge the knowledge gap between trawl and image results.

The ongoing *Nephrops* video/photo surveys offer an ideal opportunity to collect ancillary environmental data. These include all kinds of three-dimensional sediment structures, trawl marks, conspicuous epifauna like sea pens, Anthozoa, echinoderms, other Crustacea, demersal fish, sediment types, etc. Institutions undertaking *Nephrops* video surveys are already collecting a number of biological features not directly connected with *Nephrops*. They are listed in Table 8.1. It should be discussed whether other data can be retrieved from their video records once they are available for other purposes. All kinds of extra- and anecdotal data are a valuable datum for environmental assessment and habitat description.

8.1 Complementary studies

8.1.1 UK-AFBI

A good example for adding additional value to *Nephrops* studies are complementary beam trawl catches of the epifauna. Northern Ireland (AFBI) performs trawl surveys of the western Irish Sea *Nephrops* grounds during April and August each year, with the August survey taking place immediately before the collaborative UWTV survey with the Marine Institute. In addition to this trawl survey a two-metre beam trawl is deployed and towed for 5 minutes at each station (Figure 8.1), either before or after trawling with the *Nephrops* net. After hauling the beam trawl catch is emptied onto a 2 mm sieve and washed thoroughly with seawater. Megabenthos caught in the beam trawl are identified and counted. Species encountered include several burrow dwelling species such as *Calocaris macandreae*, and *Goneplax rhomboides*, in addition to *Nephrops norvegicus* (Table 8.2). These data contribute towards interpretation of the images collected during the UWTV survey and also form part of a time-series database which is providing information on the spatial distribution of species in relation to fishing effort and environmental factors, such as sediment structure, in the western Irish Sea ecosystem.

Working Document 3 (Annex 2) investigates the distribution of *Nephrops* burrow densities in relation to various environmental metrics. The plan for further work is to investigate by-catch data and infaunal data from grab samples are being used to derive general biological community distributions across the Western Irish Sea which may also have notable differences in their *Nephrops* burrow densities.

8.1.2 IR – MI

In Ireland the collection of habitat and ecosystem data is specific objective of the survey design (Annex 2, WD 2). For example the Aran survey is used of the UWTV survey to estimate the densities of other shellfish and benthic organisms and to record evidence of trawl activity. Multibeam and backscatter information is acquired to define the sedimentary transition zones as well as to identify different types of benthic habitats. Sediment samples are collected to ground truth the multibeam data and examine the relationship between sediment and burrow density (Annex 2, WD 2). In addition the sub-bottom profiler is collected to give some new insights into the sediment thickness throughout the ground. Oceanographic data are collected on a CTD section from 9o30W to 11o00W at 6 km intervals on the 53o00N and in 2007 there plan is to have a sledge mounted CTD to collect temperature, salinity, conductivity, and turbidity throughout the ground.

8.1.3 UK- FRS and UK- UMBSM

UMBSM has recently provided information to Scottish Natural Heritage (SNH), in two as yet unpublished reports, on the impact of trawling and creeling on *Nephrops* grounds in an area of NW Scotland by considering the megafauna visible in UWTV records from the grounds. This included UWTV on a ground unfished by either method for over 30 years because of naval activity. FRS was also involved in some of this work and made available some archived video. All video used was primarily taken to enumerate *Nephrops* burrows using standard sledge methods on the grounds. UMBSM, HCMR and FRS have collaborated in looking at ways of evaluating *Nephrops* trawling impacts, including use of the UWTV sledge that is used in *Nephrops* burrow survey. Among other things, the work categorized the seabed using a scale of biogenic (natural) and anthropogenic disturbance (Coggan *et.al.*, 2001). UMBSM routinely takes information on burrowing megafauna from UWTV tracks on *Nephrops* and other grounds for research purposes.

8.2 Sediments

Nephrops distribution is highly dependent on sediment type and sediment type may be used as a predictor for the presence of *Nephrops* and possibly as to relative density (e.g. Annex 2, WD 2). Sediment analysis is sometimes undertaken during *Nephrops* surveys. Laboratories tend to have their own analysis protocol, but they follow similar methodologies. Sediments are divided routinely into sand, silt and clay fractions. The sand fraction is normally analysed by dry sieving and the silt and clay by a wet methodology (pipette analysis, specific gravity, coulter counter, laser particle size analyser). The common methods are sieve analysis coupled with either pipette analysis or laser analysis. Methodologies are well described in Folk (1974) and Bale and Kenny (2005). There are a number of individual classification scales which depend on the median grain size of the sediment. Other grain-related descriptors include percentage composition of major groups (sand, silt, clay), average grain size (mean, median or modal), size frequency distributions, kurtosis, skewness, co-efficient, and water content).

Other good sedimentary environment descriptors include benthic biomass (as total macrofauna or by group/taxon division), organic carbon and chlorophyllous pigments, all relating to food availability and general level of eutrophication. While sediment parameters are conservative by nature, with almost no change over time except with large physical impacts (very long term fishing or storm events in shallower water), food related parameters are much more variable over time and space.

8.3 Future Data requirements

From the standpoint of habitat and ecosystem assessment all information from the seabed is valuable and useful. The coverage of routine surveys is typically on well used *Nephrops* fishing grounds. Survey could be extended to fulfil habitat monitoring requirements on other sediment types. A time-series of video transect may reveal important information is that about anthropogenic alterations of the natural conditions by fishing (trawls, aquaculture activities etc.).

The sledge and drop-camera systems used for *Nephrops* work are regularly used to ground-truth sidescan sonar and multibeam bathymetry data (e.g. WD 2). There has been increasing requirements for habitat mapping with UWTV which involves qualitative and quantitative assessment of benthic communities (e.g. MESH http://www.searchmesh.net/). CEFAS and the Marine Institute have also use UWTV cameras to collect images at aggregate extraction sites and dredged material disposal sites.

Table 8.1: Extra and anecdotal data recorded during *Nephrops* surveys; x = regular; (x) = option.

	UK-FRS	UK-UMBSM	UK-CEFAS	IR-MI	FR--IFREMER	GR-HCMR	PT-IPIMAR	NZ-NWIA	UK-AFBI	DK-DIFRES	SWE**
Epifauna general	x	(x)	(x)	x	(x)	(x)	(x)	(x)	x	(x)	(x)
Trawl marks	x	x	x	x	x	(x)		(x)	x	(x)	(x)
Sediment structures	x	x	x	X		(x)	(x)	(x)	(x)	(x)	(x)
Video	x	x	x	X	(x)	x	x		x	(x)	x
Photo	x	x	x	(x)				x	(x)	(x)	(x)
sonar		x	(x)	x	(x)	(x)			(x)		
Sediment chemistry		(x)		(x)		(x)		(x)	(x)		
Sediment composition	x	x		x		(x)		(x)	(x)		
Other benthos	x	(x)		x	(x)			(x)			

*** TV survey to begin in 2007**

**** TV survey to begin in 2008**

Table 8.2: Typical catches of epibenthic megafauna and other species catches from 5-minute beam trawl deployment in the Western Irish Sea.

Station		1	35	30	8	107	208	209	109	102	106	103	105
Calocaris macandreae			2		54	47			85	41	2	2	
Cancer pagurus	*brown crab*	24					123	48					
Crangon spp		2			8	6		17	2	4	396	396	52
Dichelopandalus bonneri	*pink shrimp*	85			83	53	46	28	43	24	36	36	4
Eupagurus spp					1					1	2	2	3
Euphausids					2	4		51	5				
Goneplax rhomboides			1	1		2				1	4	4	
Hyas spp	*spider crab*			2									
Jaxea nocturna			2	4									
Liocarcinus depurator				2						3	8	8	10
Macropodia spp	*spider crab*			1									
Nephrops norvegicus	*Norway lobster*	650	133	325	62	50	694	43	31	114	81	81	3
Pasiphaea sivado	*ghost shrimp*				3	16		34	122	2			
small pandalids									2	2			14
Asterias rubens	*common star*		1	1	2						1	1	7
Astropecten irregularis													15
Brissopsis			1										
Ophiothrix fragilis	*brittle star*												4
Sepiola spp		1	4						1				
Aphrodite	*sea mouse*										1	1	
Glycerids		4			2	1		1					
Nephtys spp			1		2	2			1				
Mud tubes					3				3				
Buccinum undatum	*whelk*												1
Nucula		17		1	2	6		224	19		1	1	
Nudibranchs	*sea slugs*										4	4	
Turretella communis	Turret shells						26416						
Mytilus edulis	blue mussel	5											
Micromesistius poutassou	blue whiting			1							1	1	
Gadus morhua	cod												1
Callionyrus lyra	dragonet										3	3	
Rhinonemus cimbrius	four bearded rockling	1	14	23									
Lesueurigobius friesii	Fries goby		3						4				
Melanogrammus aeglefinus	haddock	6	22		4		2						
Hippoglossoides platessoides	LRD	22	4		1	1		3	10	3	4	4	6
Trisopterus esmarkii	Norway pout			1									
Pleuronectes platessa	plaice												3
Agonus cataphractus	pogge	4											
Trisopterus minutus	poor cod		1										
Arnoglossus laterna	scaldfish		1										
Buglossidium luteum	solenette						1						
Microchirus variegatus	thick backed sole		1		2	2					2	2	
Merlangius merlangus	whiting								1				
Glyptocephalus cynoglossus	witch	12	8		3	2	5	24	5	2	2	2	

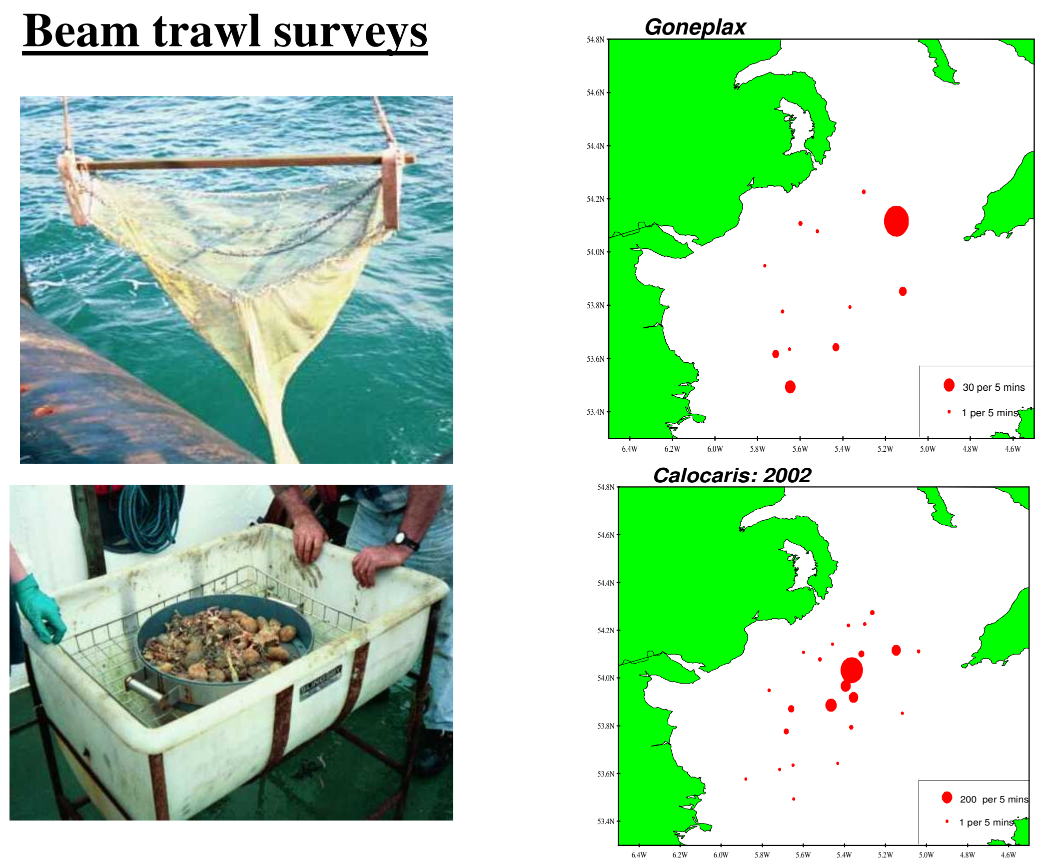

Figure 8.1. Example results from the Northern Ireland (AFBI) beam trawls surveys in the Western Irish Sea.

9 Recommendations

WKNEPTV Recommendations	To	Timeframe
1. Countries should evaluate their cameras and instrument systems to ensure they "are fit for purpose" in the context of other systems in use.	WKNEPTV Participants	ASAP
2. Dialog should be established with this SGFOT on the various optical technologies available. This might lead to a ToR in SGFOT.	WKNEPTV, FTFB and SGFOT	ASC 07
3. The WK recommends that statistical evaluations of all survey design should be carried out to see if survey effort can be reduced without a loss in precision or accuracy.	WKNEPTV Participants	ASAP
4. For each survey area, a reference set of video runs or images should be produced, along the lines of the approach typically used for otolith reading.	LRC WKNEPTV Participants	ASC 07
5. Calibrations between counters (in-house) and ringtests (between labs) should be placed on a formal basis (e.g. the UK NMBAQC system http://www.nmbaqcs.org) using video material on DVD shared between the relevant laboratories.		
6. A burrow-identification training workshop be convened with the purpose of training existing counters and production of a set of reference material for future training.		
7. A common protocol for the counting of burrow complexes be adopted (taking into account findings of this Group and the further analyses proposed in point 4).		
8. A common data exchange format of burrow counts should be adopted to facilitate inter-laboratory comparisons of counting performance.		
9. Methodologies should be developed to create an objective scale to describe tow quality rather than the current rather subjective descriptions.		
10. Recounts should be made in isolation on recorded footage	WKNEPTV Participants	ASAP
11. Further statistical analyses be made into the influences on individual's counter performance, including the practice of concurrent counting and the effect of sea-state on at-sea counting.	WKNEPTV Participants RMC	ASAP
12. Investigations should be conducted into survey design, taking into account specific survey objectives and known information on sediment distribution and spatial variability in *Nephrops* density.	WKNEPTV Participants RMC	ASAP
13. The potential for making use of the TV survey in the current year in the harvest ratio calculation should be considered	RMC, AWGs	2008
14. Further exploration of the non-equilibrium simulations including more biological realism, uncertainty and errors in TAC implementation is required	RMC, WGMG, AWGs	2008
15. The 20% harvest ratio can be considered a reasonable starting point for deriving harvest ratio based TACs given perfect TAC implementation. The harvest ratio may need to be adapted in the future depending on observed stock response. Further work on addressing some of the accuracy and bias issues in surveys (particularly edge effects and occupancy) described in Table 6.8 maybe needed.	AWGs, RMC, ACFM, WKNEPTV Participants	2008
16. The use of UWTV surveys to inform alternative (not TAC and effort) management systems should be explored further. For example UWTV surveys might be particularly useful to identify closed areas, closed periods or restrictions of fishing time.	AWGs, ACFM	As necessary
17. *Nephrops* UWTV video transects should be used for habitat mapping and ecosystem assessment and made available for that purpose.	WKNEPTV Participants	As necessary
18. Countries should proactively develop databases and data models that will improve data exchange and access to UWTV data and footage ahead of the new DCR requirements.	WKNEPTV Participants	By 2009

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Annex 2: Working documents

Working Document 1:

Using UWTV in crustacean trawl surveys, as a tool for *Nephrops* stock assessment

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Abstract

UWTV equipment was attached onto the headline of the trawlnet, pointing forward, towards the direction of the trawl, in order to obtain video footage of the sea floor. The quality of the images obtained with this gear was consistently good. The still images extracted from the video have also proven to be suitable for counting *Nephrops* burrows. The UWTV equipment can be further improved by fitting a range finder that would provide an accurate distance reading from the camera do the sea floor.

Introduction

The Norway lobster *Nephrops norvegicus* is the single most important crustacean species within the crustacean trawl fishery in Portuguese waters, followed by the pink shrimp *Parapenaeus longirostris*. Due to its high economic value it provides an important income for the majority of the crustacean trawlers. As such, a sound management of this fishery is paramount to ensure the economic feasibility of the fleet as a whole. For this purpose the Portuguese *Nephrops* stocks (SW and S fishing grounds) have been assessed every two years for the last 20 years during ICES working groups. However, due to declining trend in abundance, assessments have been produced on a yearly basis for the last 5 years (ICES, 2005). Assessment work is based on the population structure, landings and fishery-independent abundance estimates (i.e. crustacean trawl surveys). However, there are several problems associated to the latter, including differences in the catchability according to season, size and sex of the animals. To curb this problem, British researchers at the Scottish Office for Agriculture, Environment and Fisheries Department (SOAEFD) suggested the use of UWTV as a means for counting its burrows in order to produce direct abundance estimates (Bailey *et.al.*, 1993; Marrs *et.al.*, 1996; Froglia *et.al.*, 1997; Tuck *et.al.*, 1997). This research group has, in fact, pioneered the use of such technology, having most of the work been carried out in the North Sea. Their work yielded consistent results and has proven suitable for estimating *Nephrops* abundance. Moreover, the ICES Advisory Committee on Fishery Management (ACFM) has recommended that UWTV surveys should be further used to provide biomass estimates (ICES, 2003). This same technology is, however, difficult to apply in Portuguese *Nephrops* grounds as they are considerably deeper than those in the North Sea, Baltic, Irish Sea, Kattegat, Skagerrak, etc., where several studies have already been successfully conducted. For this particular reason, a number of adaptations to both the method and equipment had to be made in order to obtain good quality video footage of *Nephrops* grounds.

Methods

As referred above the majority of the work done in this field has mainly been conducted in relatively shallow waters using equipment such as ROVs or UWTV cameras mounted on sledges, generally with umbilical cords which convey live footage over to the vessel. This method has, nevertheless, proven unsuitable, or highly impractical, for working at depths greater than 250 m. As such, a different approach was tested.

General equipment configuration

It consisted in mounting a camera directly onto the headline of the trawlnet coupled to an autonomous underwater video recorder (UWVCR). Using an UWVCR fully eliminates the need for an umbilical cord to supply both electrical power and a means to convey the video signal to vessel. To be able to attach the camera directly to the headline a purpose-built stainless steel part was designed and assembled as shown in Figure 1. It was mounted so that the camera to pointed forward at an approximate angle of 45º relative to the sea floor. Due to the absence of light at these depths a highly sensitive camera and a light source were used, as specified in Table 1. This type of mounting conferred great stability to the camera as a result of it being attached to the ∞22 mm steel headline, which, during the fishing operation, works under great tension. Indeed, for the purpose of this study obtaining a consistently stable image was crucial to be able to recognize and subsequently count all *Nephrops* burrows.

Deployment and operation details

Due to the sensitivity of the UWTV equipment extra care was taken during its deployment. The imaging gear was lowered with a pulley system to avoid damage.

Video Capture

The UWVCR (a Sony® Hi8 VCR packed within a titanium alloy casing) was fitted with a programmable time-lag recording device so that it started capturing images only after the trawl gear acquiring its operational shape. This allowed capturing images moments before the gear touching the sea floor and thereafter (continuous recording). This device is important as it optimizes the total recording time available (generally 60 minutes) by avoiding the capture of unnecessary footage.

For this purpose the camera was setup to start recording 20 min after its deployment and to stop 1 h after, just before hauling the net back up on to the vessel.

Once in the vessel, the video tape removed from the UWVCR and viewed to check the suitability of the footage for subsequent analysis.

Table 1 Specifications of the camera Kongsberg - OE1324 Enhanced SIT Low Light.

GENERAL SPECIFICATIONS	
Horizontal Resolution	**700 TV Lines (typical)**
Light Sensitivity (limiting)	**2 x 10 $^{-4}$ Lux (faceplate)**
Light Sensitivity (full video)	**1 x 10 $^{-3}$ Lux (faceplate)**
Grey Scale	**10 Shades (RETMA)**
OPTICAL, ENVIRONMENTAL AND MECHANICAL SPECIFICATIONS	
Depth Range	**3000 m**
Standard Lens	**6.5 mm f/1.8**
Iris Control	**Automatic Light Control**
Focus Control	**Fixed, (150 mm to infinity)**
Angle of View	**86° Diagonal (nominal) in water**
Water Compensation	**Plano-Concave Acrylic Port**
Weight	**Air 4.6 Kg - Water 2.2 Kg**
Standard Housing	**6 Al / 4V ASTM B 348 Titanium Alloy**
Light Source	**12 V – 50 W underwater halogen light bulb**

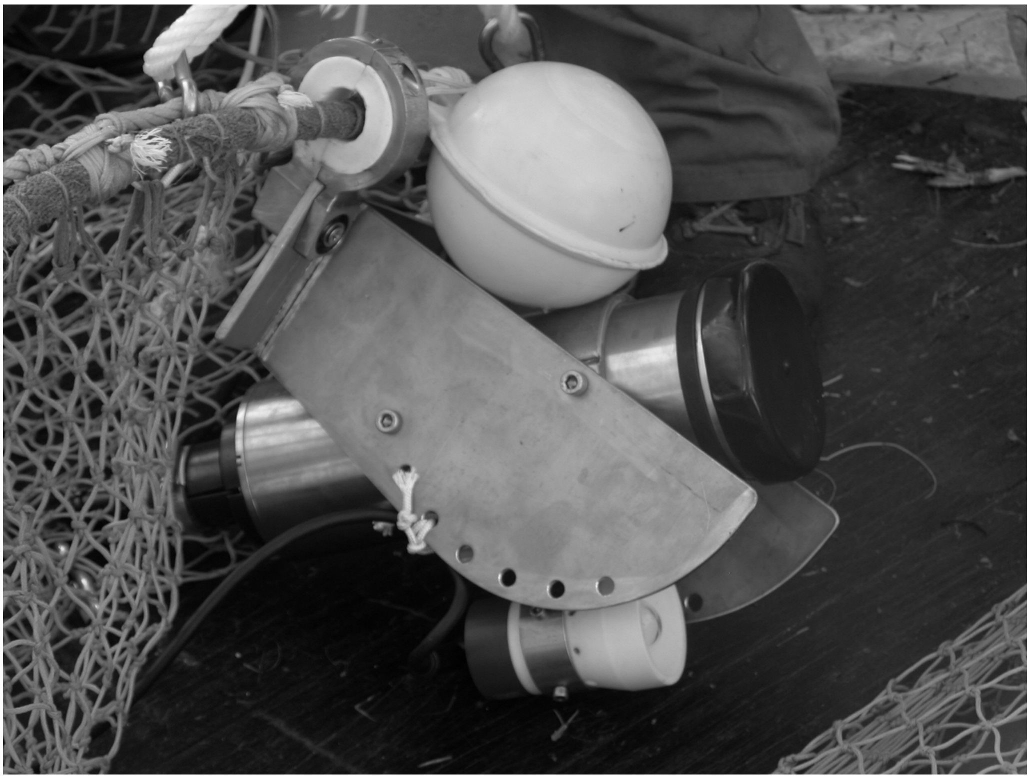

Figure 1 Camera mount on the headline.

Results and Discussion

The majority of the studies into *Nephrops* burrow density found in literature (op cit.), refer to work carried out in shallow waters. In contrast, the images shown here were not only obtained at much greater depths (500+ m) but also using a different methodology. All images (Figure 2) were extracted directly from video footage by means of video editing software. The stills' overall quality and resolution were found to be adequate for further processing, e.g. estimation of size of the animals and counting burrows. During the tests, despite no range finder or other direct distance measuring instruments being used, it is possible to estimate the field of view by knowing the height of the camera relative to the sea floor, given by a SCANMAR height sensor. It is, however, important to notice that the actual results from the burrow counts are beyond the scope of the present communication. The main objective is, solely, to validate the feasibility of using the described equipment and methodology for counting *Nephrops* burrows as well as suggesting other possible applications using the same gear, yet with different mounting on the trawlnet.

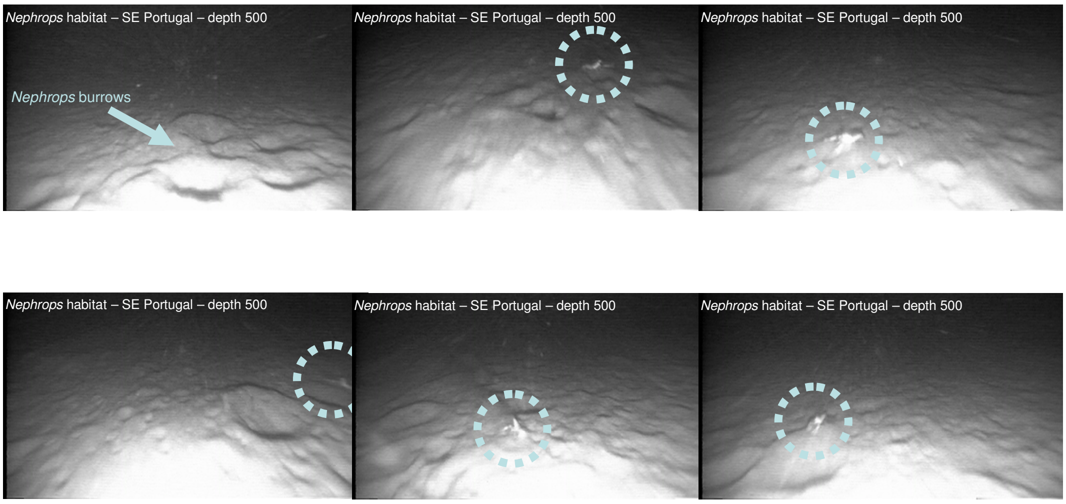

Figure 2 *Nephrops* burrows and *Nephrops norvegicus*, where indicated. Images collected at 500 m deep in known *Nephrops* grounds off the south Portuguese coast.

As such, the above images clearly show the suitability of the equipment for counting burrows for subsequent estimation of total biomass in designated grounds. In fact, should additional sensors be fitted, e.g. range finder, depth meter, path length and/or a twin laser pointing device, its overall performance would be greatly improved, as the additional data output would allow an easier estimation of the actual size of the lobsters and their burrows. There are, of course, many other possible uses for the collected data to be used under different scopes, such as assessing animal behaviour at the moment of catch, the impact of the otter boards on the sea floor, etc.

One of the major advantages of this approach is that it provides not only a suitable technical solution for obtaining good quality images of the sea floor for estimating burrow density, but also a means of calibrating these estimates by comparing the number of burrows with total catches for each trawl. This is particularly important as it eliminates the need for dedicated TV surveys, which are expensive and time consuming. Indeed, this method has proven to be sufficiently adaptable to suit the needs of many different types of work. During the testing of the equipment several deployment configurations were tried, including attaching the camera onto the middle section of the trawlnet (inner part of the top pane) either pointing forward or backwards. This was achieved by sewing a 1.5 m steel cable section to the mesh (perpendicular to the direction of the movement), to which the camera attaches. This configuration provides an insight as to how the animals react at the opening of the net (with camera pointing forward), as well as how they behave after the first physical contact with it (with camera pointing backward).

The only drawback regarding the use of UWTV technology during bottom trawl surveys is that it increases the turn-around time for each trawl as a result of the extra care needed to avoid damaging the equipment during both deployment and hauling operations. Nonetheless, the overall benefits of using this method during trawl surveys seem to outweigh this drawback by far. Incorporating these two objectives in a single survey leads to a significant reduction in research costs since this type of work was hitherto carried out separately during single purpose surveys.

Further work using this methodology and new UWTV equipment, is expected be conducted during the 2007 crustacean survey and in depth results published after analysing the obtained data.

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Working Document 2 to WKNEPTV 2007

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

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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, multibeam 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 and landings in the autumn and a positive relationship between observed densities and landings the following spring.

Introduction

The prawn (*Nephrops norvegicus*) are common around the Irish coast occurring in geographically distinct sandy/muddy areas were the sediment is suitable for them to construct their burrows. The 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 randomized 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^{o}30W to 11^{o}00W at 6 km intervals on the 53^{o}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.

Material and methods

Scientific Personnel

NAME	SERVICE AREA	ROLE
Colm Lordan	**MI-FSS**	**Scientist in Charge**
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Imelda Heir	**MI-FSS**	**Fisheries Scientist**
Turloch Smith	**MI-FSS**	**Fisheries Scientist**
Deirdre O'Driscoll	**MI-OSS-AMS**	**Surveyor**
Chris Allsop	**MI-SPDS**	**Database developer**
Fergal Dywer	**MTDS**	**Electronics Technician**

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

Survey Plan

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 randomized start position provides the best statistical compromise between a totally randomized 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 meaning 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.

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.

Oceanographic operations

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

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.

Equipment and system details and specifications

UWTV Equipment

The equipment used during the UWTV survey is provided below:

- UWTV Sledge (MTDS spec)
- 1 0E14–366 Underwater Video Camera (Angle XX, 12 mm from sleeve, with a bottom of the screen measurement of 96/72 cm in air/water)
- 4 Miniature Underwater Lamps (2 used for duration of survey)
- 2 OE1232 Control Units
- 1 300 Meter NC 13 Cable
- 1 10 m 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

Navigational Positioning

The primary positioning for this survey employed the Fugro Starfix 3100LRS DGPS. The specified accuracy for Starfix VBS is 2.0 m (horizontal) and 5.0 m (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 and P/R/H Source)
- Seapath GPS Position (Secondary Position Source)
- EM1002S – Centre beam (Nadir) depth

- EA400 – 33 KHz and 210 KHz 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 (IMUs) and the Global Positioning System (GPS). The system utilizes 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 echosounder (MBES)
- EA400 Singlebeam echosounder (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.

EM1002S Multibeam echosounder (MBES)

The principal system employed for the recording of bathymetric data throughout the survey was the Kongsberg Simrad EM1002S multibeam echosounder. The transducer is hull mounted on the vessel and operates at a frequency of 95 kHz to 93 kHz. 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.* SVPs 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 four 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 these corrections, a refraction on multibeam data was observed for most of the survey. This was probably caused by the presence of a strong thermocline.

Bathymetry EA400 SBES

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

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 settings adopted during the survey are given in below in Table 2. Interrogation of the beacon was set at 3.0s and a frequency of 1.95 kHz 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.

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.

Beam Trawl operations

The beam trawl used had a 4 m beam, chain footrope, 80 mm standard diamond mesh netting in the top-sheet and belly and a 20 mm codend line. A warp to depth ratio of 3: 1 was used and towing speed was around 2.8 knots. Navigational data were 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.

Grab sampling

A Duncan and Associates day-grab was used for sediment sampling. After the 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 laser-particle size analysis at each station. Positional data were logged for each sample using STARFIX and in the survey multilog database.

Analysis methods

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 visibility, ground type and speed of the sledge during one-minute intervals were subjectively 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 burrows 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 standardized 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.

$$\overline{Z}_i = \frac{1}{n_i}\sum_{j=1}^{n_i} z_{i,j}$$

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

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

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

$$CV_{sam} = S.\,E./\,\overline{Z}_i$$

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

$$B_i = A_i * \overline{Z}_i$$

Where A_i is the stratum area.

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

$$Var[Bi] = \frac{A_i^2 * s_i^2}{n_i}$$

All the calculations above ignore the spatial covariance 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 midpoints of each UWTV transect were converted to an absolute measure in kilometres form a point roughly in the middle of the grounds, $53^{o}00$ N and $10^{o}04.2$ 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 $\infty(h)$, 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

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

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

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 standardized 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.

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 20 m resolution using and plotted using SURFER Version 8.02 and krigging interpolation.

Particle Size Analysis of sediment data

The PSA of the sediment samples was carried out by the University of Plymouth using a Low Angle Laser 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.

Results

The positions of all sampling events are 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 s section on 53°N from 11°W to 10°W (approximately 52nmil), 4 SVPs and 4 stations were fished with the beam trawl.

Nephrops UWTV results

All stations were counted by two burrow counters independently. Comparisons 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 12 km 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 7a and spatially in 7b.

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 gesotatistical analysis provides a slightly lower variance estimate compared with the empirical approach. The geostatistical coefficient of variation estimate ranges between 25–46%.

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 80 m along the eastern flank to over 110 m 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 northwestern flank and protruding ridge in the southeastern corner.

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.

Oceanographic Conditions

The Aran Grounds is oceanographically characterized as and area of low energy and not much current activity. The temperature close to the seabed 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^{o}C and a shallow thermocline was apparent close to the surface with surface temperatures reaching 16^{o}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^{o}15W of the bottom density current which sets up in this area from the salinity profiles. The transmissmometer 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.

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 bycatches 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 20 mm carapace length.

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.

Discussion and Conclusions

All survey objectives were successful 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 and 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 interannual 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 are 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 interannual 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 the relationship between burrow abundance and landings was examined (Figure 14). The fishery can be characterized 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 be 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 are 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.

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Appendices

Appendix 1 Survey Narrative CV0510 Aran UWTV 2005

1 June 2006

Mobilization 9: 00. Scientific party join vessel during the day as required. Scientific briefing 16: 15. Safety tour 18: 40. Vessel departed Galway docks at 19: 45. Muster drill 20: 20.

2 June 2006

At Station 4 STARFIX programme crashed but was successfully retrieved and day Grab successful on fourth attempt in 98 m of water. At Station 3, Grab successful on third attempt in 100 m 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. Station13, 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 redeploying also USBL batteries changed. SVP (SoundVelocityProfile) 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 initialize 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. Recommenced 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 4.16 300 m 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 demobilization.

8 June 2006

Vessel was fully demobilized.

Table 1 R. V. Celtic Voyager operational payload systems and datasets collected on the Aran *Nephrops* UWTV survey 2006.

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

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

SUPERVISION SCREEN	PARAMETER	SETTING ADOPTED
Acoustic Array	**Interrogation Frequency**	**19 500 Hz**
	Environment	**Normal**
GPS	**Baud Rate**	**9600 Bauds**
	Protocol	**GPGGA**
	Parity	**None**
	Stop Bit	**1.0**
Output	**Period**	**499 ms**
	Baud Rate	**19 200 Bauds**
	Parity	**None**
	Stop Bit	**1.0**
Processor	**Position Cycle Recurrence**	**3s**
	Acoustic Recurrence	**Internal Fixed**
	Recurrence	**3s**

Table 3 Summary parametric statistics for the *Nephrops* UWTV surveys of the Aran and adjacent grounds form 2002–2006.

Ground	Year	Number of stations	Area Surveyed (M^2)	Burrow count	Mean Density (No./M^2)	Var	Standard Deviation	Standard Error	t-value	95%CI	CV_{iid} (Relative SE)	Domain Area (km2)	Raised abundance estimate (million burrows)
Aran Grounds	2002	49	9,450	7,599	0.81	0.19	0.43	0.06	2.01	0.12	7.6%	978	794
	2003	42	11,398	11,652	1.09	0.17	0.41	0.06	2.02	0.13	5.9%	978	1,062
	2004	64	13,040	18,742	1.38	0.43	0.66	0.08	2.00	0.16	6.0%	978	1,346
	2005	70	12,373	13,321	1.06	0.26	0.51	0.06	1.99	0.12	5.8%	978	1,032
	2006	67	10,527	6,928	0.61	0.10	0.31	0.04	2.00	0.08	6.2%	978	600
Galway Bay	2002	7	1,299	2,017	1.58	0.14	0.37	0.14	2.45	0.34	8.8%		n/a
	2003	3	591	941	1.60	0.09	0.29	0.17	4.30	0.73	10.6%		n/a
	2004	9	2,312	1,625	0.73	0.18	0.42	0.14	2.31	0.32	19.4%		n/a
	2005	4	661	1,107	1.67	0.04	0.20	0.10	3.18	0.32	6.0%		n/a
	2006	3	522	522	1.01	0.06	0.25	0.15	4.30	0.63	14.5%		n/a
Slyne Grounds	2002	5	1,216	1,027	0.85	0.04	0.19	0.08	2.78	0.23	9.9%		n/a
	2003									0.00			
	2004	3	827	531	0.68	0.07	0.27	0.15	4.30	0.66	22.7%		n/a
	2005	3	531	294	0.55	0.00	0.05	0.03	4.30	0.13	5.6%		n/a
	2006	3	526	210	0.41	0.04	0.20	0.11	4.30	0.49	28.1%		n/a

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

Ground	Year	Number of stations	Number of boundary points	Mean Density (No./M^2)	Var	Standard Deviation	CV_{geo}	Domain Area (km2)	Raised abundance estimate (million burrows)
Aran	2002	49	27	0.82	0.10	0.32	39%	892	753
Aran	2003	42	27	0.89	0.16	0.41	46%	894	817
Aran	2004	64	26	1.49	0.16	0.40	27%	889	1369
Aran	2005	70	28	1.14	0.08	0.28	25%	886	1047
Aran	2006	67	26	0.69	0.05	0.23	33%	889	635

Table 5. The results of beam trawl catches on the Aran Grounds in June 2006.

	Start				End				Distance	Swept Area
Beam Trawl	Date	Time	Longitude	Lattitude	Date	Time	Longitude	Lattitude	over ground	(m2)
Tow 1	06.01.80	20:00:50	52.87986	-10.09709	06.01.80	20:29:43	52.90329	-10.09914	2212	8849
Tow 2	06.01.80	21:02:11	52.95423	-10.08851	06.01.80	21:30:48	52.97617	-10.0871	2404	9615
Tow 3	07.01.80	02:15:00	53.02103	-10.08247	07.01.80	02:40:22	53.039	-10.08156	2449	9796
Tow 4	07.06.06	03:14:31	53.08309	-10.05584	07.06.06	03:41:33	53.1026	-10.05025	2620	10480

	Weight of *Nephrops* Caught (kg) in each tow					
Beam Trawl	Males	Female Pale	Female Medium	Female Dark	Female Ogiverous	Total
Tow 1	3.598	0.02		3.999		7.617
Tow 2	2.378	0.073		2.584		5.035
Tow 3	0.197		0.018	0.189		0.404
Tow 4	1.421	0.057	0.239	2.225	0.031	3.973

	Number of *Nephrops* Caught in each tow					
Beam Trawl	Males	Female Pale	Female Medium	Female Dark	Female Ogiverous	Total
Tow 1	224	6		296		526
Tow 2	189	16		200		405
Tow 3	17		1	15		33
Tow 4	109	11	18	143	1	282

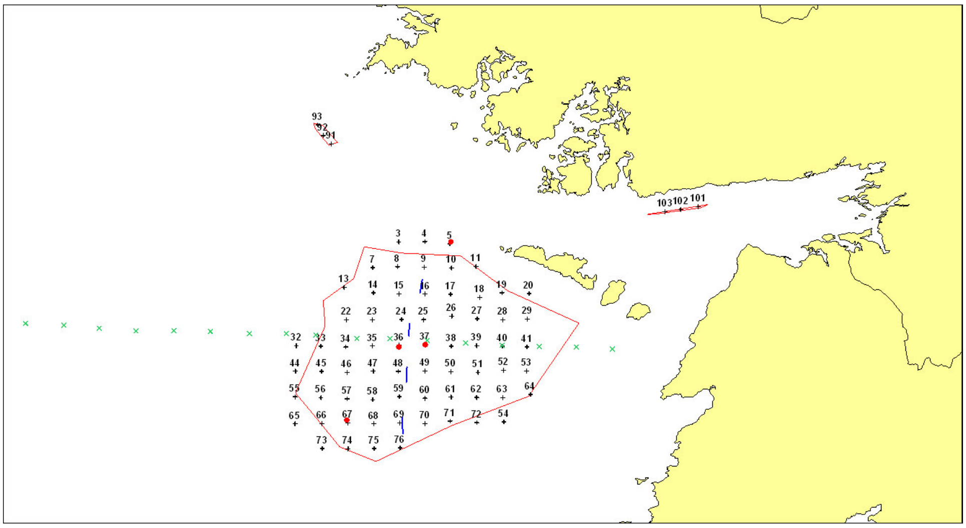

Figure 1. The positions of all sampling events during the Aran UWTV survey 2007. The UWTV stations are shown as numbered '+'s, SVPs are shown as red dots, beam trawls are the blue lines and CTD stations as green x's. The boundary of the ground is annotated as a red line.

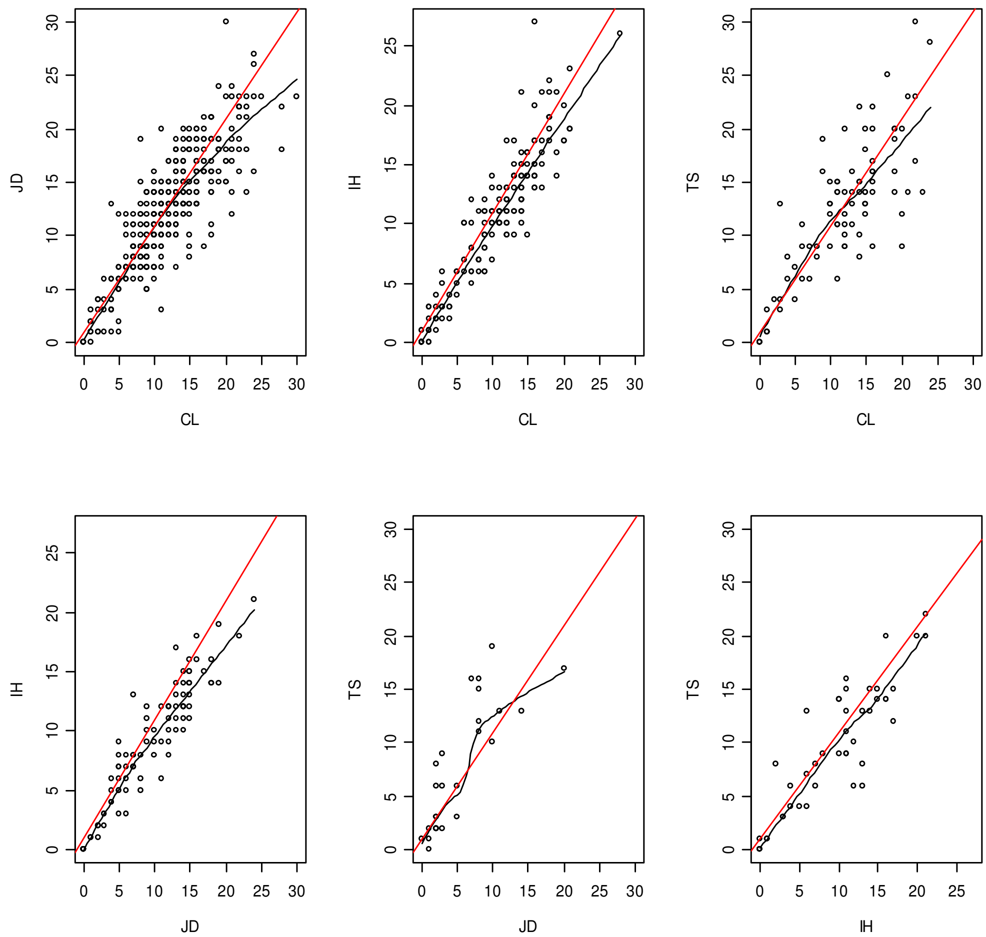

Figure 2. Scatterplot comparisons on inter-reader counts on a minute by minute basis. The red line indicates perfect agreement and the black line is a lowess smoother.

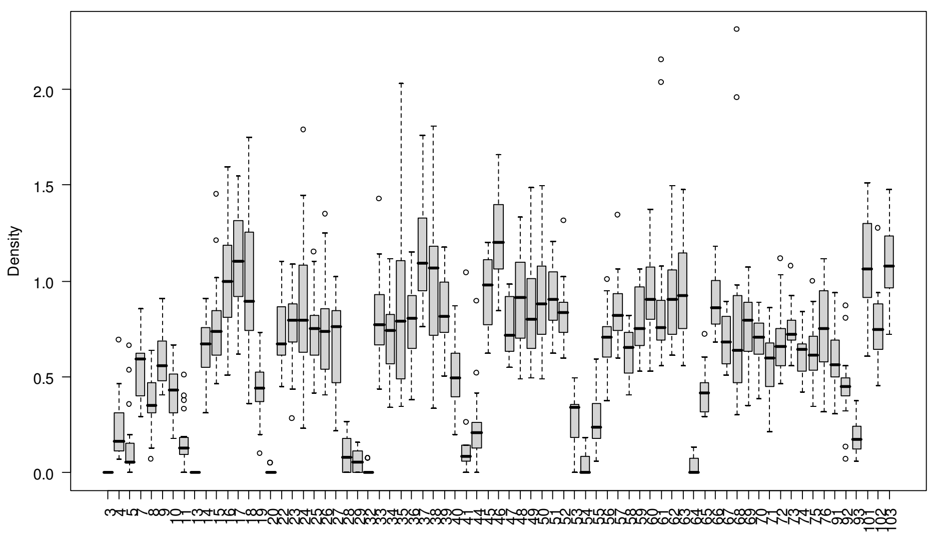

Figure 3. Box plots of the minute by minute burrow density estimate for the Aran grounds 2006.

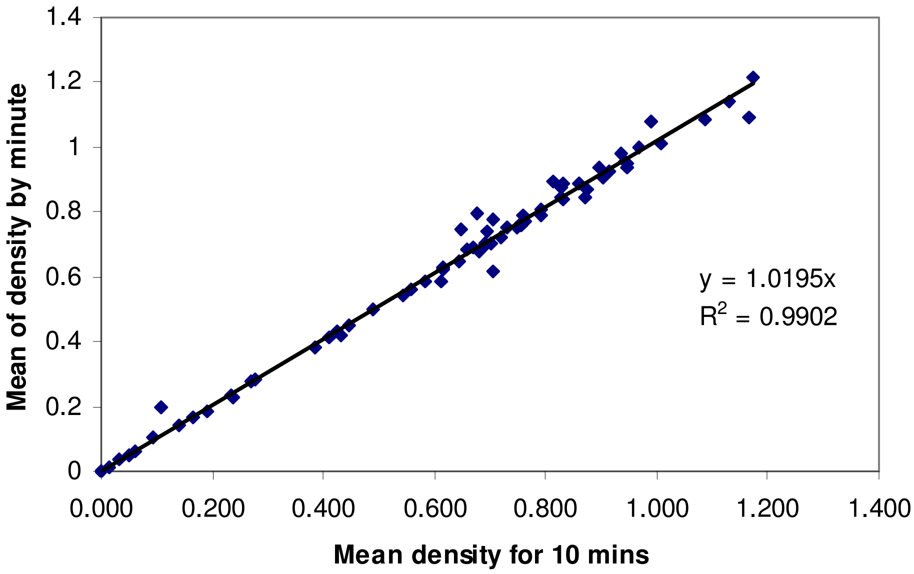

Figure 4. A comparison of the estimated mean density of burrows for each station vs. the mean of the minute by minute burrow density estimated for the Aran grounds 2006.

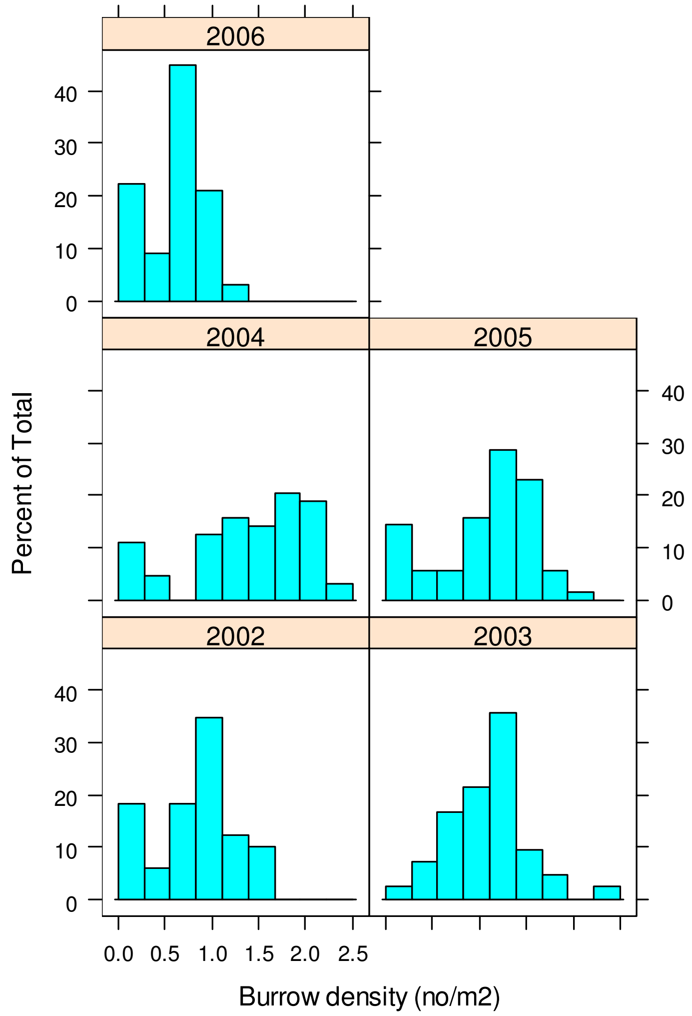

Figure 5: Burrow density distributions for the Aran Grounds by year from 2002–2006.

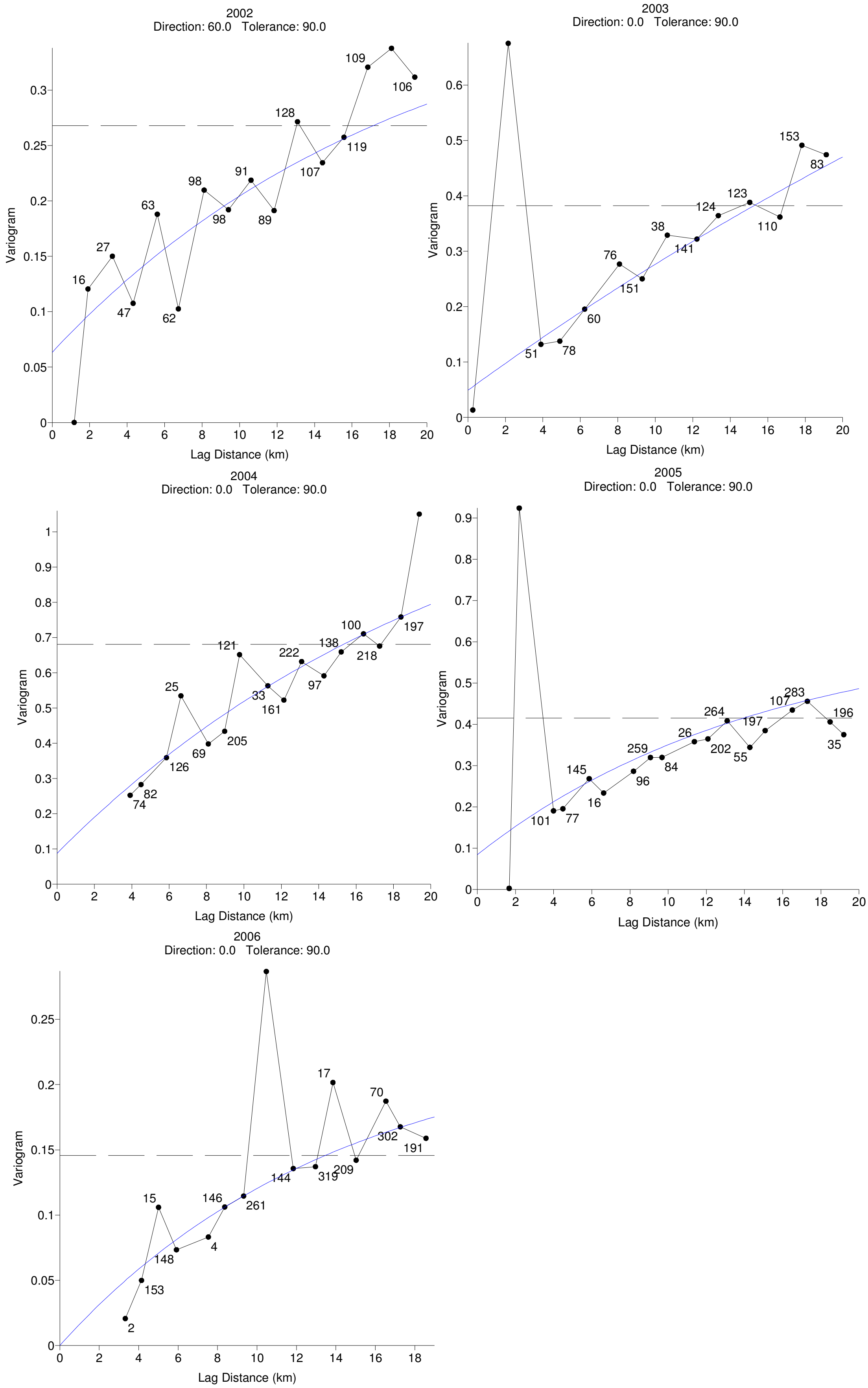

Figure 6: Omnidriectional mean variograms for the Aran Grounds by year from 2002–2006.

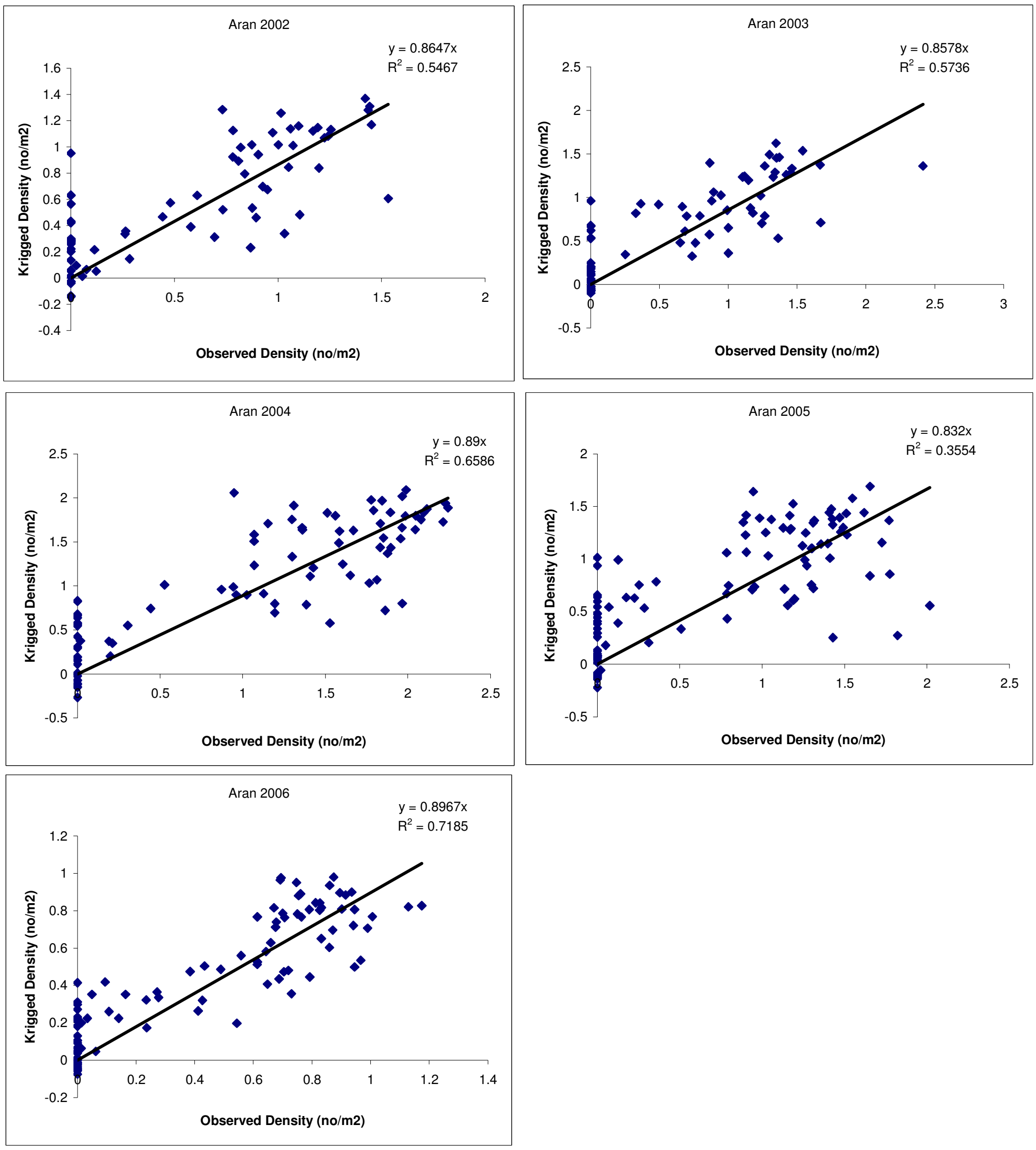

Figure 7.a: Cross validation plots for the Aran Grounds by year from 2002–2006.

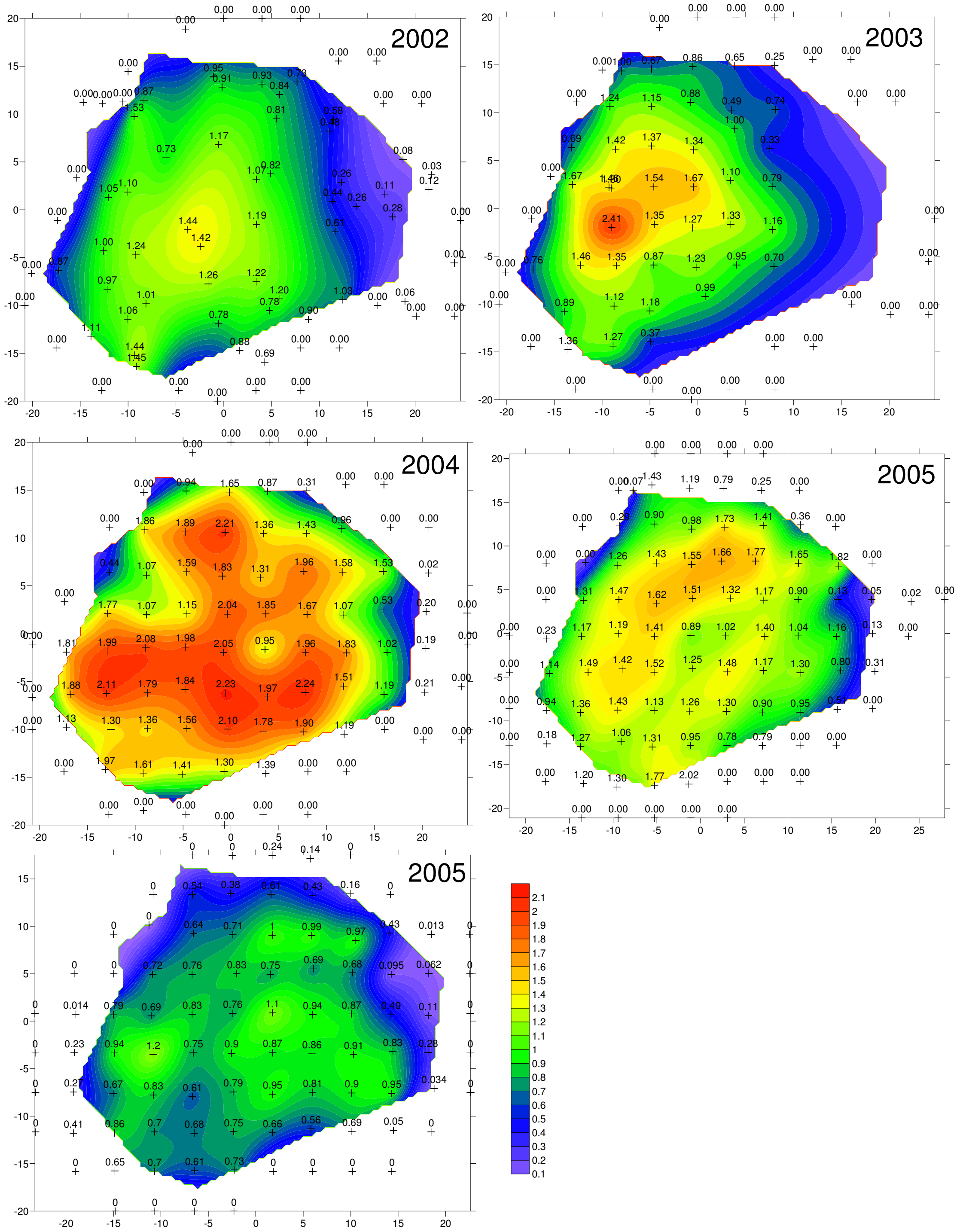

Figure 7.b: Contour plots of the krigged density estimates for the Aran Grounds from 2002–2006.

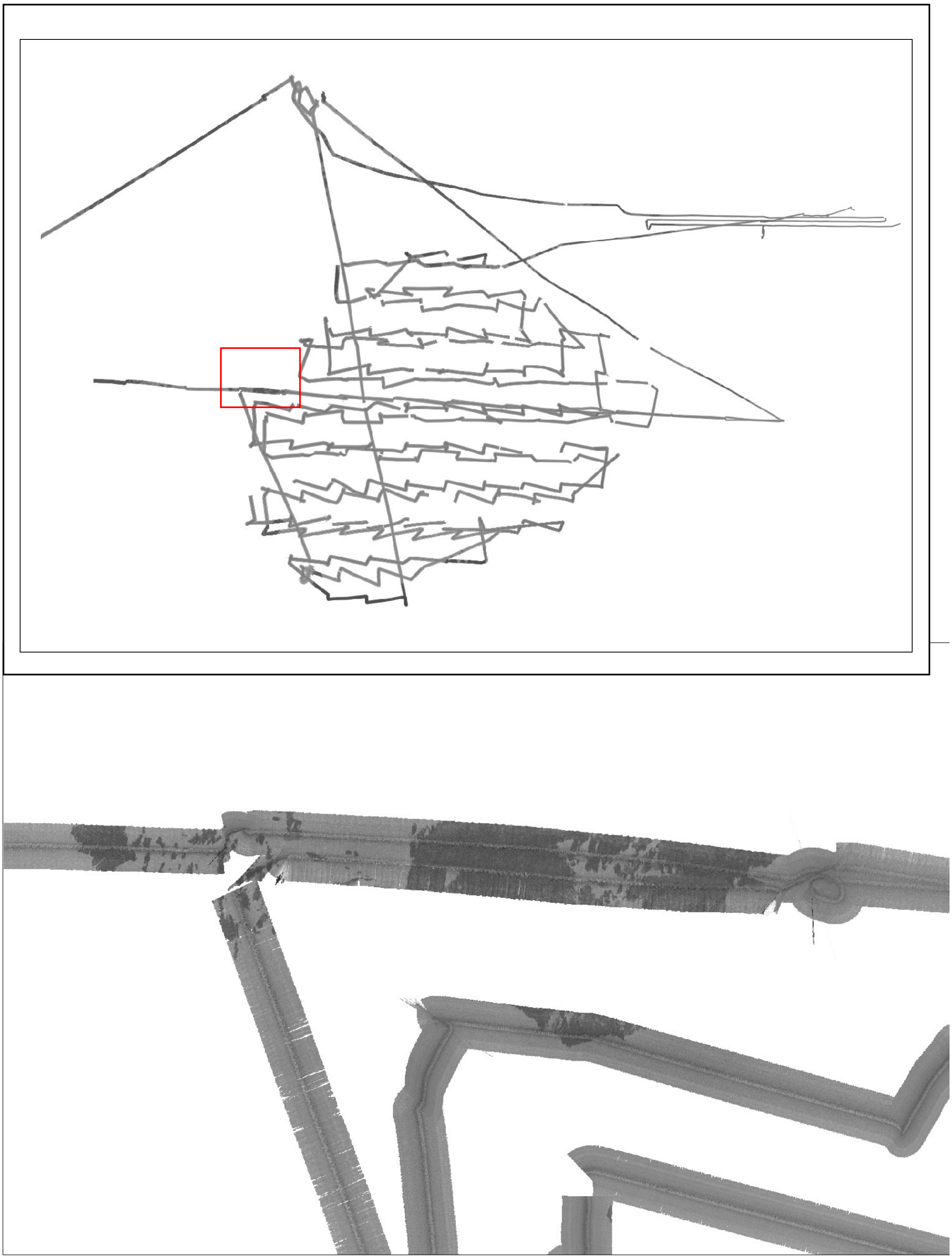

Figure 8: a) Multibeam backscatter data for the Aran Grounds survey in 2005 and 2006. b) a zoomed in section of the multibeam data showing rocky outcrops around the boundary of the ground.

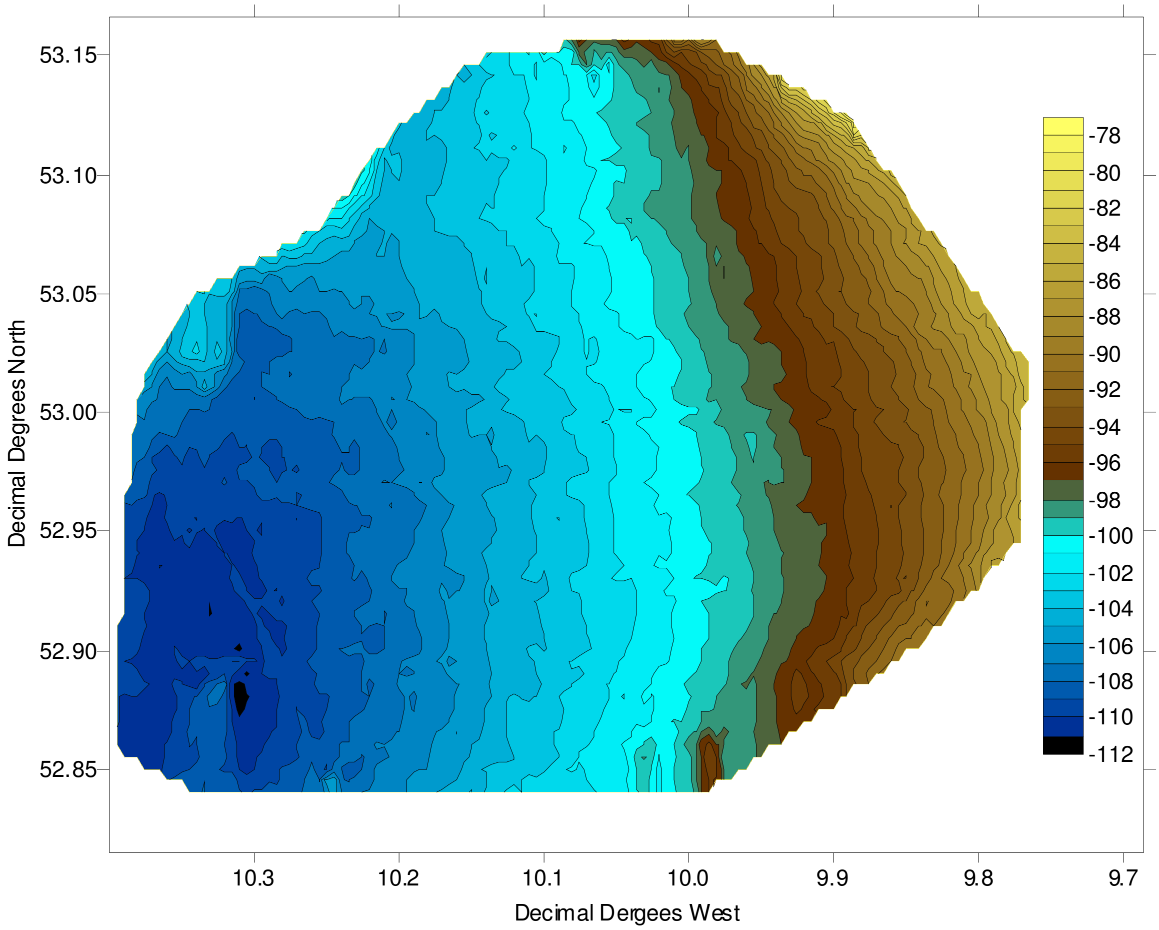

Figure 9. The bathymetry of the Aran grounds.

a)

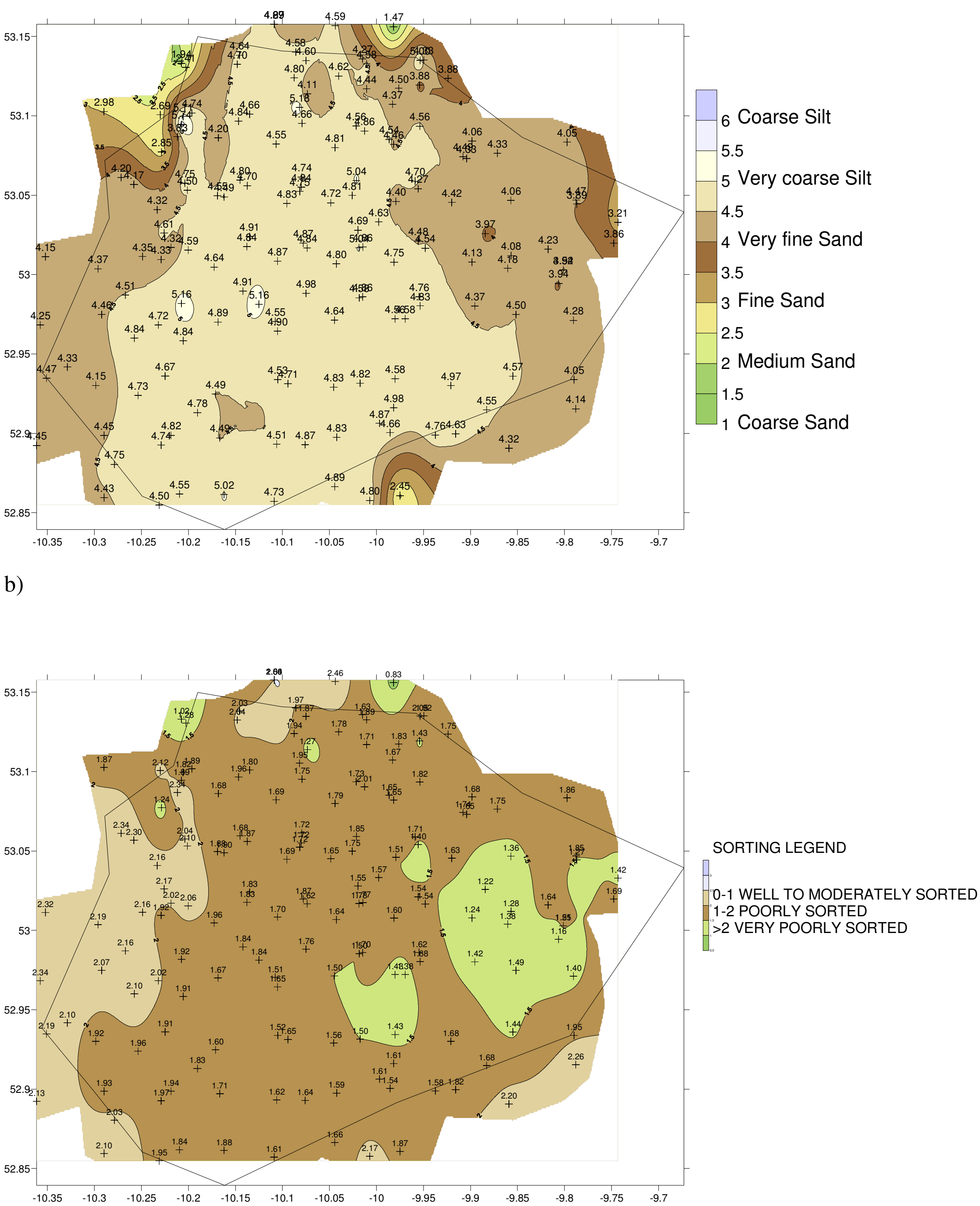

Figure 10. Contour and post plots of the a) mean size (phi) and classification based on the Friedman and Sanders (1978) scales and b) sorting (σ_g) of the sediments on the Aran Grounds based on PSA results from samples collected from 2002–2006.

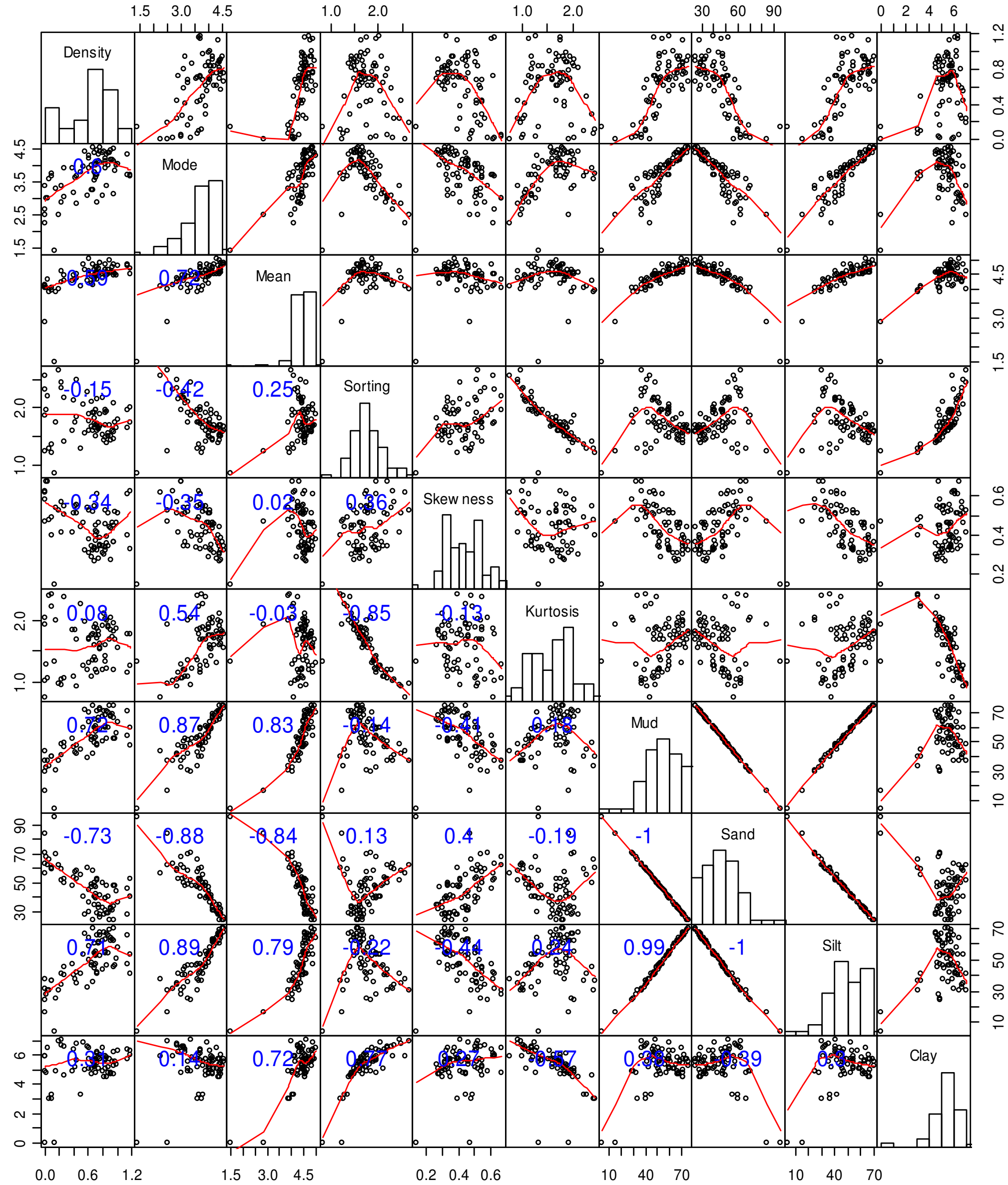

Figure 11. The relationship between *Nephrops* burrow density and various sediment variables collected during the 2006 Aran survey. The red lines are lowess smoothers and the blue numbers are correlation coefficients.

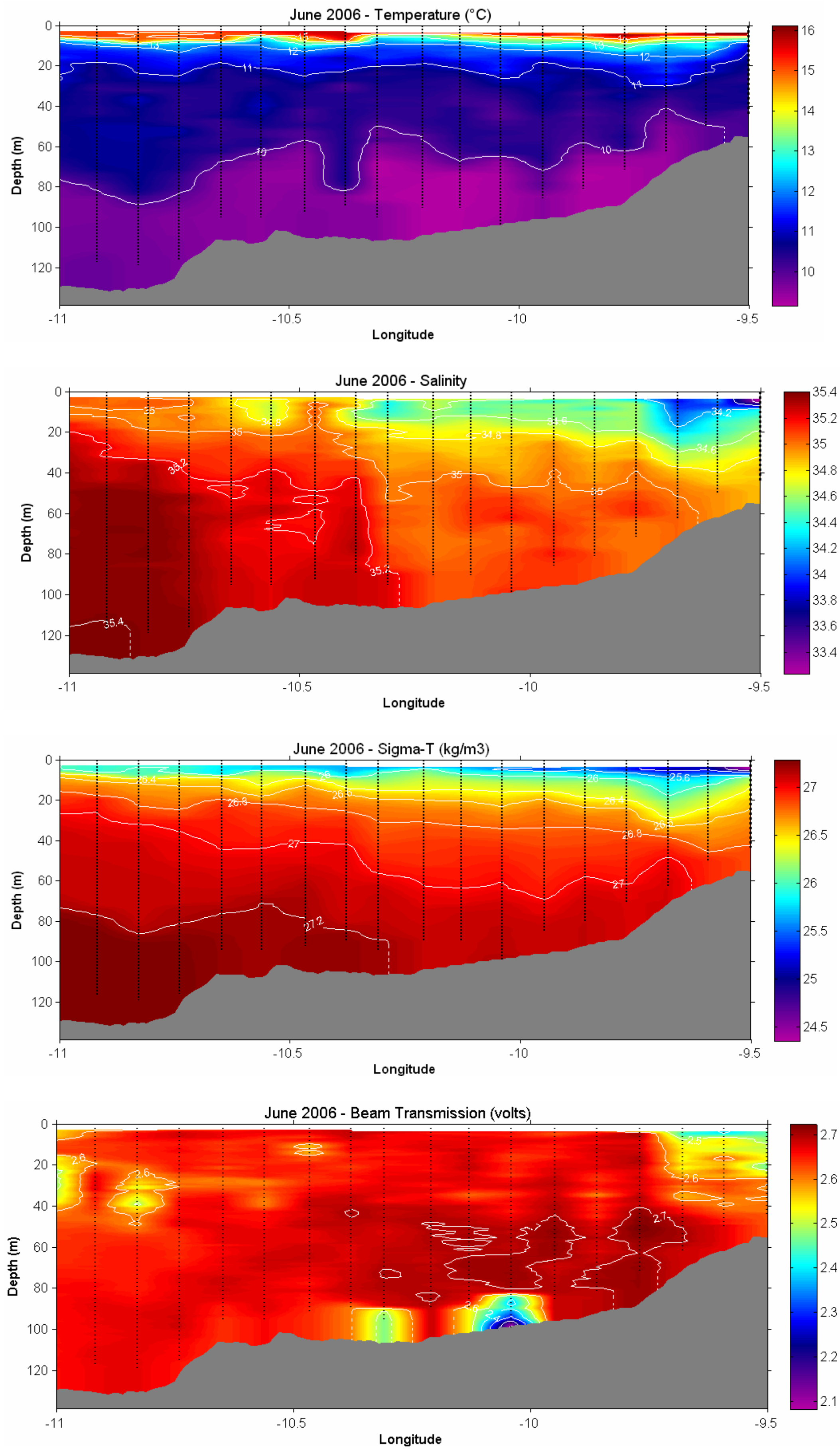

Figure 12. The CTD data collected during the Aran Ground survey in 2006.

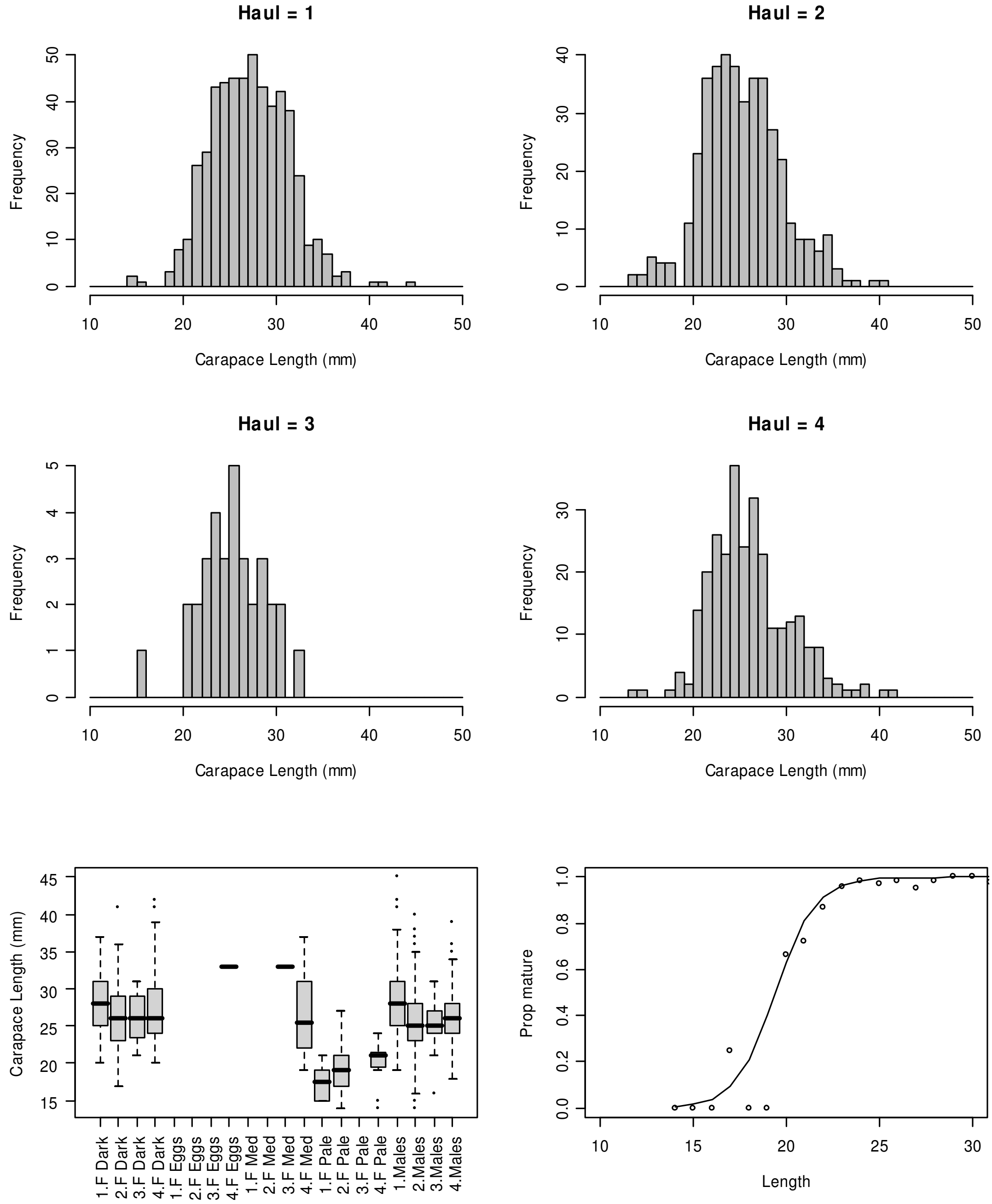

Figure 13. A summary of the *Nephrops* biological data collected; length frequency distributions by haul, box plots of mean size by macroscopic maturity and haul and a maturity ogive for female *Nephrops*.

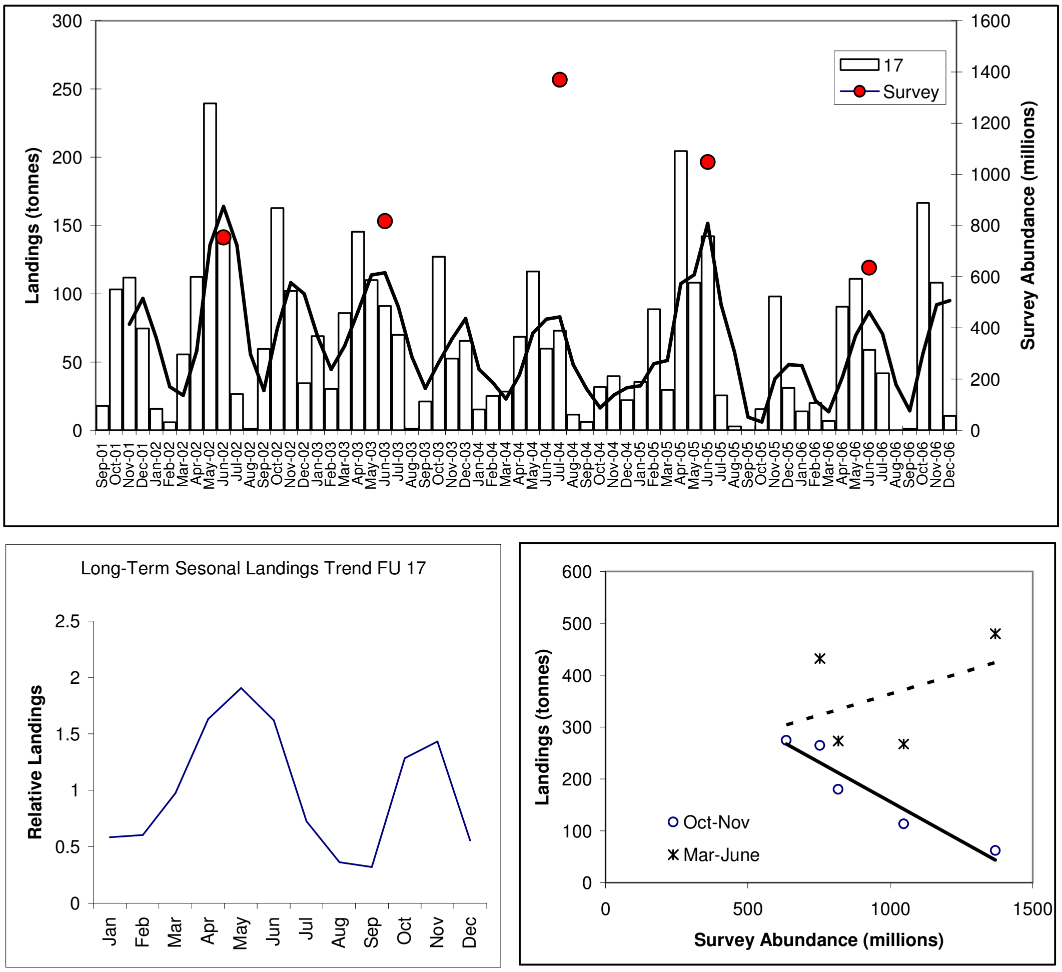

Figure 14. a) The monthly landings from FU 17 and survey abundance index b) mean standardized long term (1995–2006) seasonal trend in landings for FU 17 and c) the relationship between landings for two periods and survey abundance estimates.

Working Document 3

Modelling *Nephrops norvegicus* burrow densities from the Western Irish Sea

Not to be cited without prior reference to the authors

Annika Mitchell, Queen's University of Belfast and Richard Briggs Agri-Food and Biosciences Institute Northern Ireland.

Nephrops burrow densities (burrows per m^2) have been calculated based upon extensive underwater video surveys in the Western Irish Sea each summer since 2003 (undertaken jointly by AFBI and the Marine Institute). These data were examined with respect to temporal changes between years and spatial patterns [1]. Statistical tests revealed no significant difference between years although when the data are interpolated for each year the resulting data grids do show different spatial patterns (Annex 1).

The aim of the project was to examine environmental variables which may be important in determining burrow density throughout the Western Irish Sea, with a view to building a predictive habitat suitability model for this species. The Irish Sea has been surveyed and studied extensively and therefore a number of datasets are available relating to a range of abiotic factors. The following datasets were gathered, checked, interpolated where necessary and amalgamated into a geographical information system (GIS):

1) Bottom current data (calculated at the mid point of the bottom 1/32 of the water column, using the Proudman Oceanographic Laboratory (POL)'s CS20 model), which was divided into the following datasets (all in m/s) and interpolated to a 500 m grid:
   - 1.1) Maximum speed [2]
   - 1.2) Minimum speed
   - 1.3) U component (east-west direction current speed) at maximum speed
   - 1.4) U component (east-west direction current speed) at minimum speed
   - 1.5) V component (north-south direction current speed) at maximum speed
   - 1.6) V component (north-south direction current speed) at minimum speed

2) Bathymetric data, extracted from existing admiralty chart soundings and RoxAnn™ single beam echosounder depth data [3] gathered since 1996 by AFBI and interpolated to a 250 m grid to generate the following datasets:

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[1] Data did not meet requirements for parametric statistical tests; Kruskal-Wallis was test performed on all data from each year (2003, 2004, 2005 & 2006) and also on subsets of data which were located within 1000 m of each other. P-values indicated that H_0 (no significant difference at an α-level of 0.05) could be supported: no significant difference between years. Spatial patterns, however, indicate that there are notable differences between the locations of 'hotspots' of higher densities between each year (see Annex 1). However, the lower densities were consistently found towards the outer edge of the surveyed area.

[2] Maximum and minimum speeds were selected after examining tidal current data from 2003 to 2006 using POLPRED™ software and selecting dates and times which corresponded with the highest or lowest current speeds, respectively. Data was examined for the whole of the western Irish Sea. Maximum speed was selected as the tidal currents on 20/03/2005 at 01:00GMT, and minimum speed was selected as the tidal currents on 20/09/2005 at 10:00GMT.

[3] RoxAnn depth data was cleaned by removing jumps in navigational data and erroneous depth data as examined using a non-earth plot in GIS to highlight depth 'spikes'. Data has not been corrected to chart datum however it is adequate when interpolated over such a large area.

2.1) Bathymetry

2.2) Hillshaded bathymetry

2.3) Aspect (0–360^{o})

2.4) Slope angle

3) Sediment data, taken from laser particle size analysis of samples collected during surveys between 1997 and 2006 [4], and interpolated to a 500 m grid to derive the following datasets:

3.1) Sorting

3.2) Percentage of the silt/clay (<63μm) fraction

3.3) Median Phi

4) Broadscale modelled oceanographic parameters for the UK continental shelf, courtesy of POL: Stratification probability density function (*Sr*) (the number of days the surface to bed temperature difference at this cell exceeds 0.5^{o}C divided by number of days in this season over the 10 year run (dimensionless)) as extracted from a 10 year simulation of the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS; Holt and James, 2001). The dataset was represented as four layers:

4.1) Stratification probability density function: Spring

4.2) Stratification probability density function: Summer

4.3) Stratification probability density function: Autumn

4.4) Stratification probability density function: Winter

5) Bottom temperature was extracted from AFBI CTD measurements taken throughout the Western Irish Sea since 1992. After examining all available data and its spatial coverage, two sets of data were selected to represent near-minimum and near-maximum bottom temperature, and interpolated to a 1 km grid:

5.1) April 1993 measurements, showing near-minimum bottom temperatures

5.2) September 1992 measurements, showing near-maximum bottom temperatures

After the *Nephrops* burrow density data had been examined both statistically and using geostatistical interpolation (see Annex 1 and footnote 1 above) it was decided to use all available data from 2003–2006 as actual points (not interpolated), and to extract data from the above list of abiotic factors for each point. This resulted in a total of 449 datapoints for which co-located data existed for all the variables listed above.

The data were examined initially by a series of scatterplots (figure 1) which indicated some potential relationships. Next, the data were subjected to regression analysis, using the whole dataset. Best subsets regression analysis was undertaken to identify the variables most likely to be effective in regression modelling. Stepwise regression was also used to further support the results provided from the best subsets analysis.

Finally, four models were constructed using multiple linear regression analysis:

6) All variables: u component max., u component min., v component max., v component min., mac. Speed, min. speed, slope angle, aspect, sediment sorting,

[4] Particle size analysis (PSA) data was examined for temporal changes by using NMMP datasets for 4 sites which are sampled annually. Some significant differences were found, particularly in median phi and, to a lesser extent, in sorting with each year. However, upon examination of the available datasets throughout the Irish Sea it was felt that temporal changes were negligible and for use of this data for spatial modelling it was permissible to amalgamate data from different years to improve spatial coverage.

sediment silt/clay percentage, sediment median phi, stratification probability in Autumn, stratification probability in Spring, stratification probability in Summer, April 1993 bottom temperature, September 1992 temperature.

7) u component min., sediment silt/clay percentage, stratification probability in Spring.

8) v component max., sediment silt/clay percentage, stratification probability in Spring.

9) u component min., sediment sorting, sediment silt/clay percentage, sediment median phi, stratification probability in Spring.

The p-values for each variable, the model R-sq, R-sq(adj) and R-sq(pred) values were examined and the best performer was found to be model 4.

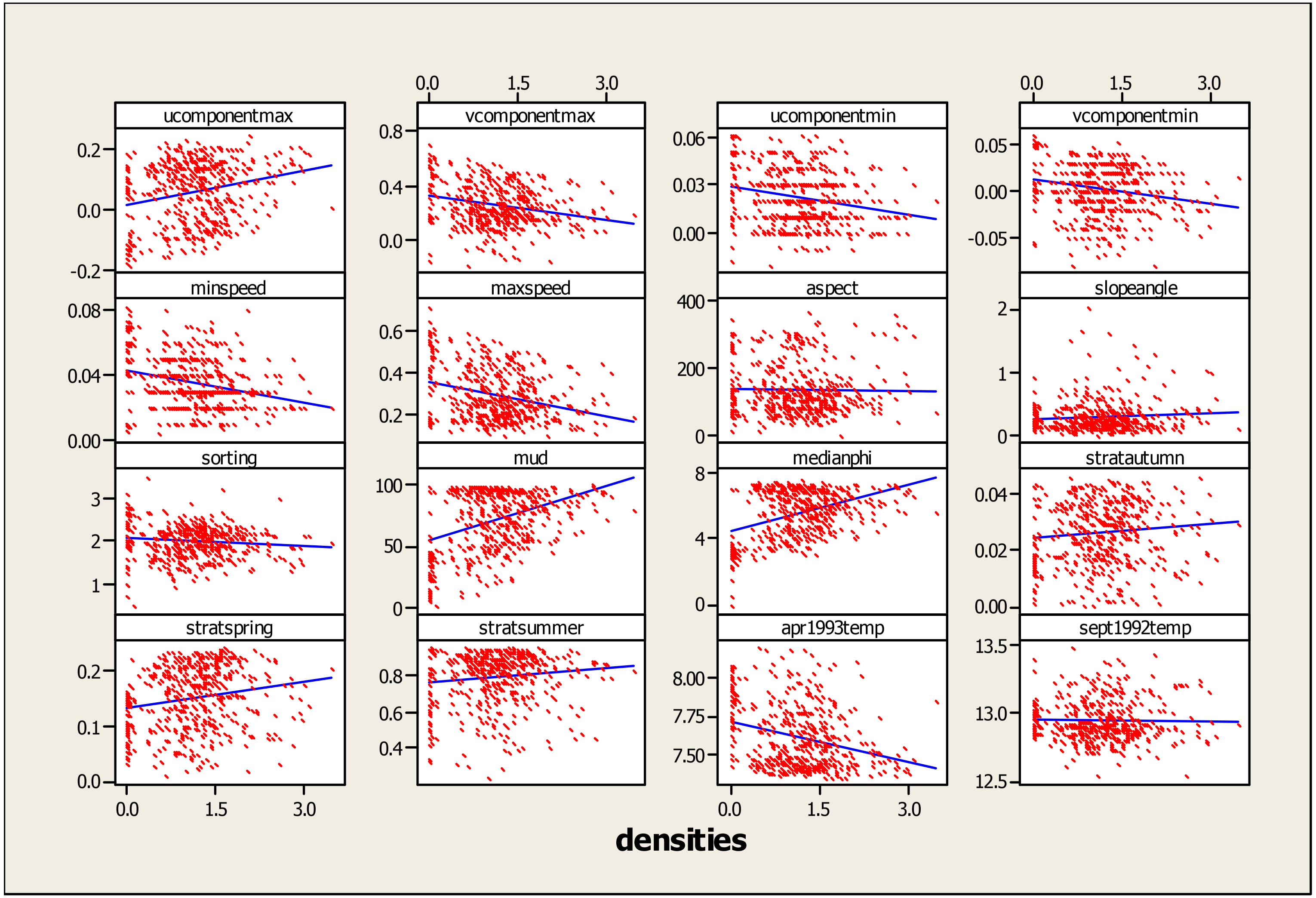


Figure 1. Scatterplots showing possible correlations between *Nephrops* burrow densities and the abiotic factors listed above.

In order to properly test the linear regression modelling approach, the data were divided into a training dataset and a testing dataset. The whole dataset was randomized and then 80% (359 data rows) were used for model development ('training') and 20% (90 data rows) used for model testing. Multiple linear regression analysis was performed for model 4 above using only the training dataset, resulting in the following model:

Burrow densities (per m^2) = - 0.22 – (8.07 u component min.) + (0.15 sorting) + (0.00399 silt/clay) + (0.115 median phi) + (1.8 stratification probability spring).

This model was then applied to the testing dataset. Finally, the predicted *Nephrops* densities generated by the model were compared to the actual densities. Where there was less than 0.5 burrows per square meter difference between the predicted and the actual densities the prediction was deemed to be good. Using this assessment, 54.4% of the predictions were good. This however drops to 28% if the acceptance level is reduced to a difference of less than 0.25 burrows per square meter. The predicted burrow densities were also examined spatially in the GIS (figure 2). In particular, it appears that the model has difficulties predicting higher burrow densities (anything above 1.6 per m^2) and dealing with 'hotspots' that are obviously due to other variables influencing burrow density.

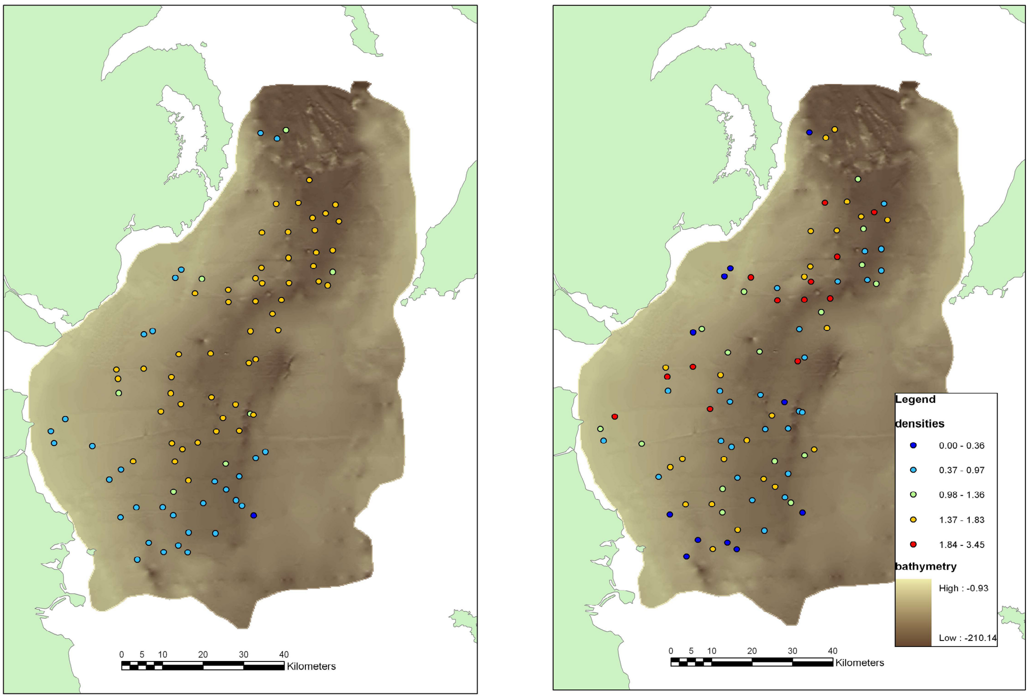


Figure 2 Predicted (left) and actual (right) burrow densities (per m^2).

In addition, it would appear that predicting zero burrow densities is also problematic. However, the model appears successful in predicting the overall distribution of the *Nephrops* ground.

Main conclusions

The linear regression modelling approach has shown that of the abiotic factors investigated the following have some impact upon burrow densities in the Western Irish Sea:

- u component (east-west) minimum current speed: higher current speeds = lower densities
- sediment sorting: more poorly sorted = higher densities

- silt/clay sediment fraction: higher silt/clay fraction = higher densities
- sediment median phi: higher median phi (finer sediment) = higher densities
- stratification probability density function in Spring: higher stratification probability = higher densities

P-values from the regression analysis showed that of these factors, u component minimum current speed was most significantly related to burrow densities, followed by the spring stratification probability and closely to that the sediment median phi. From examining the scatterplots it is quite likely that for a number of these variables the relationship with burrow density could be non-linear, and therefore linear regression modelling may not make best use of the potential predictive power of these variables.

Future work

Alternative modelling approaches are being investigated, such as the use of non-linear regression modelling, neural networks and genetic algorithms, to see if these can yield better results with the same input datasets and variables.

In addition, the potential energy anomaly (Φ), which is generally used as a measurement of stratification as it represents the amount of energy needed to mix the water column, is being calculated from actual (rather than modelled) data to see how well it supports the modelled stratification data.

Bycatch data and infaunal data from grab samples are being used to derive general biological community distributions across the Western Irish Sea which may also have notable differences in their *Nephrops* burrow densities.

Finally, at two finer-scale sites within the Western Irish Sea multibeam echosounder data will be examined to see if backscatter data may be related to burrow densities.

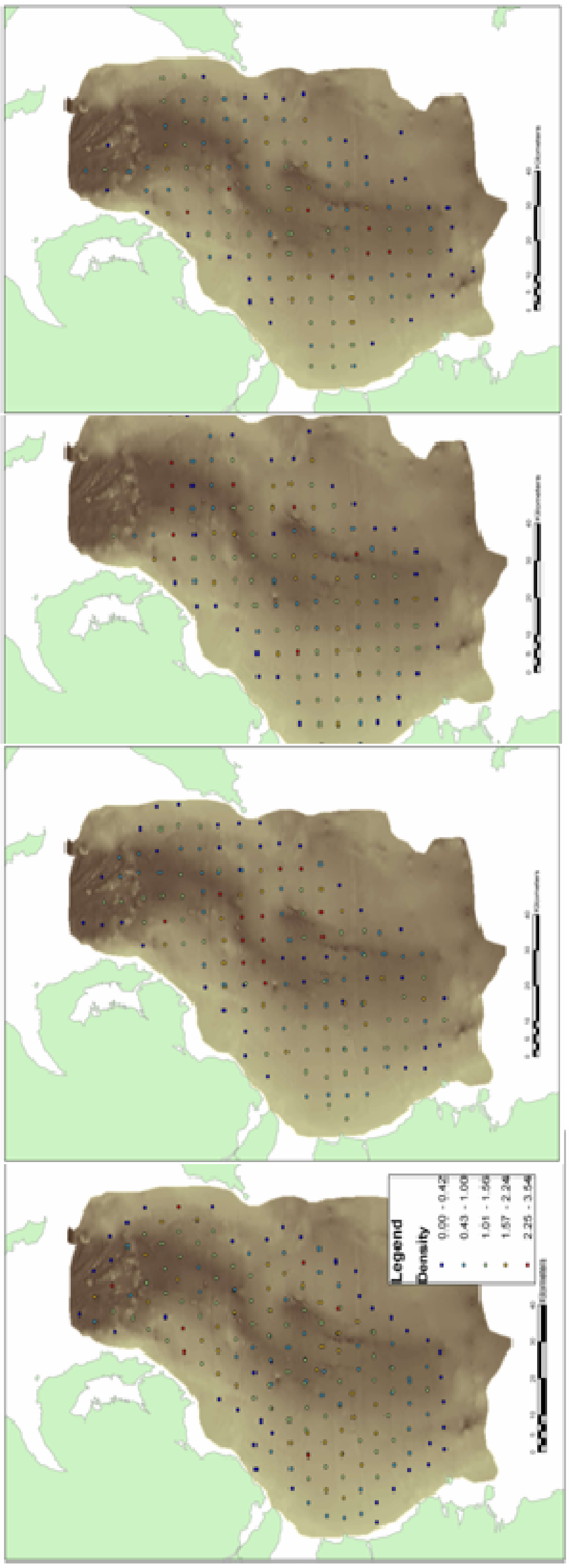


Figure 3 Burrow densities and locations overlaid upon bathymetry: 2003–2006.

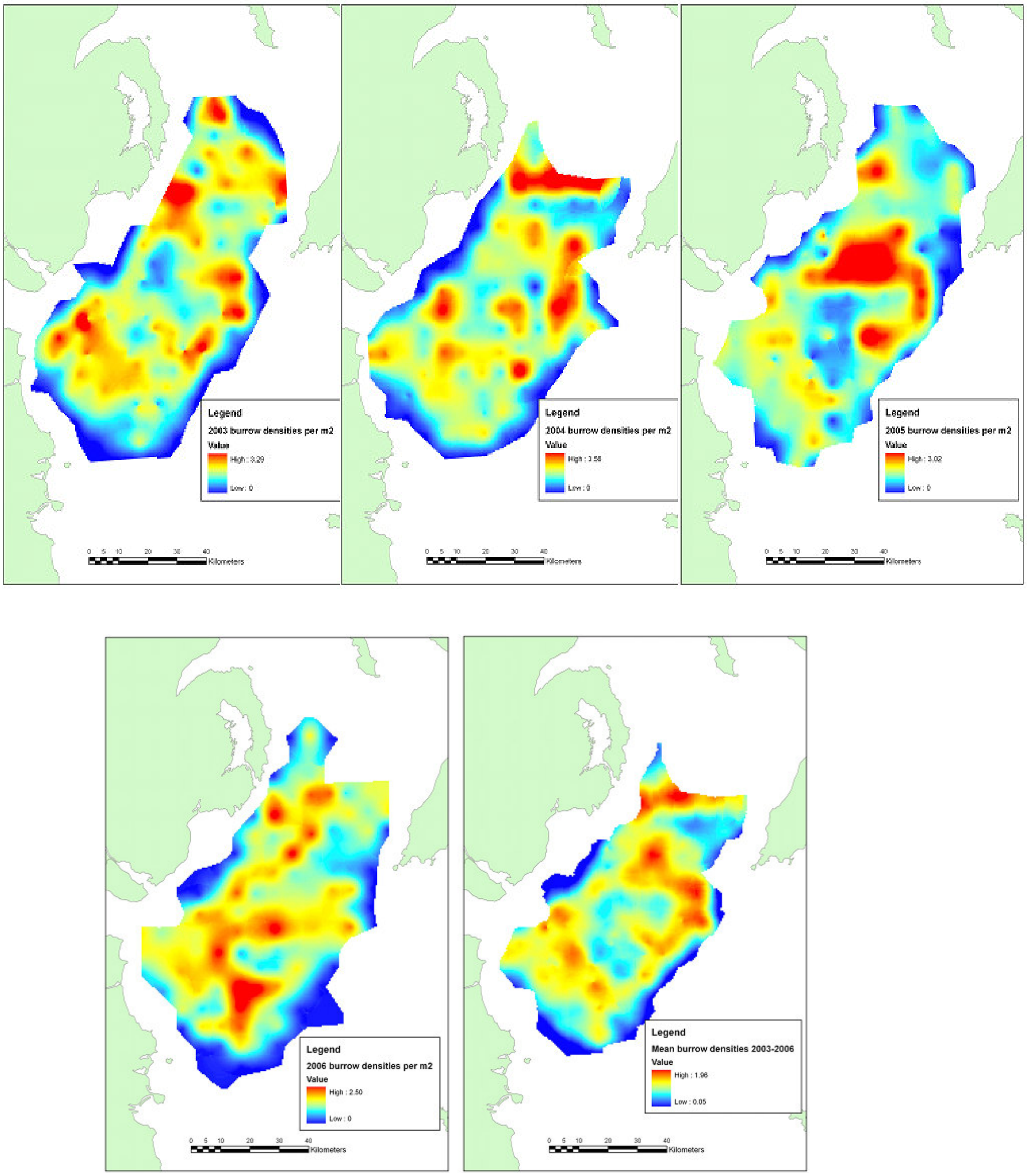


Figure 4. Burrow densities interpolated (500 m grid) for each year, using kriging and a search radius of 10000 m, and mean burrow densities calculated.

Working Document 4

FRS *Nephrops* TV Survey Design

Neil Campbell and Adrian Weetman

Introduction

In Scottish waters, most exploited populations of *Nephrops norvegicus* are found at depths of between 40 and 200 m (Howard, 1982), on fine cohesive muddy sediments suitable for burrow-building (Alfonso-Dias, 1998). The distribution of these sediments around the UK has generally been well defined (BGS, 2002) (Figure 1). The feasibility of using underwater TV surveys to estimate *Nephrops* burrow density on muddy sediments was investigated in inshore waters during the 1980s (Bailey and Chapman, 1983; Chapman, 1985, Alfonso-Dias, 1998). In 1992, RV *Scotia* carried out the first combined TV and trawling survey of the Fladen ground (Chapman *et.al.,* 1994).

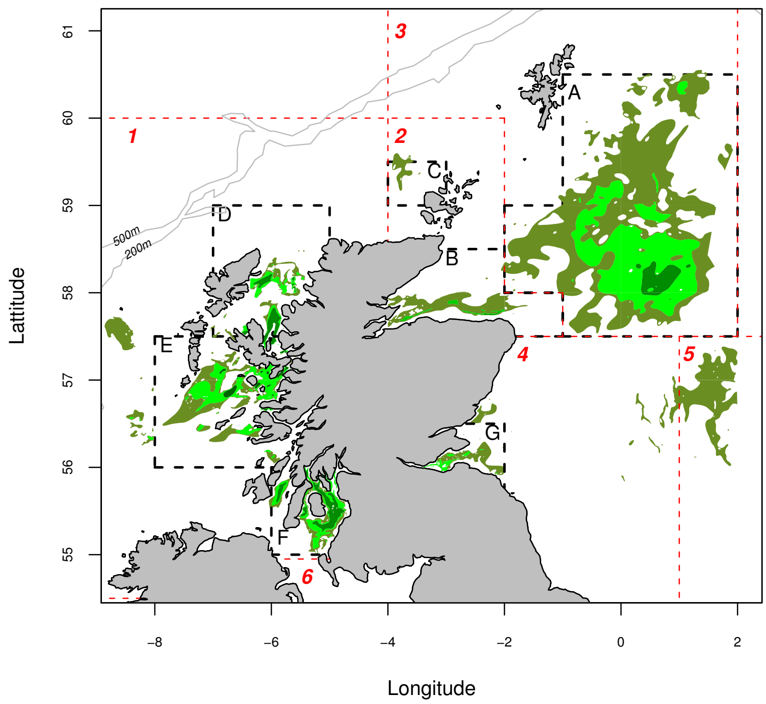


Figure 1. Areas of suitable sediment for *Nephrops norvegicus* around Scotland; olive – muddy sand, green – sandy mud, dark green - mud. Assessment areas are as follows, A – Fladen, FU 7, B – Moray Firth, FU 9, C – Noup, FU 10, D – North Minch, FU 11, E – South Minch, FU 12, F – Firth of Clyde/Sound of Jura, FU 13, G – Firth of Forth, FU 8. 1 – Management Area C, 2 – Management Area F, 3 – Management Area G, 4 – Management Area I, 5 – Management Area H, 6 – Management Area J.

Since 1992, TV surveys have been carried out on a regular basis by FRS at a number of sites around Scotland (Figure 2). Additionally, a number of sites outside these areas have been surveyed for purposes not directly related to the assessment process, such as Loch Torridon, the Buzzard oil-field, Devil's Hole or deep waters around Rockall (Figure 3). Since June 2004, TV surveys have been carried out under the EU DCR.

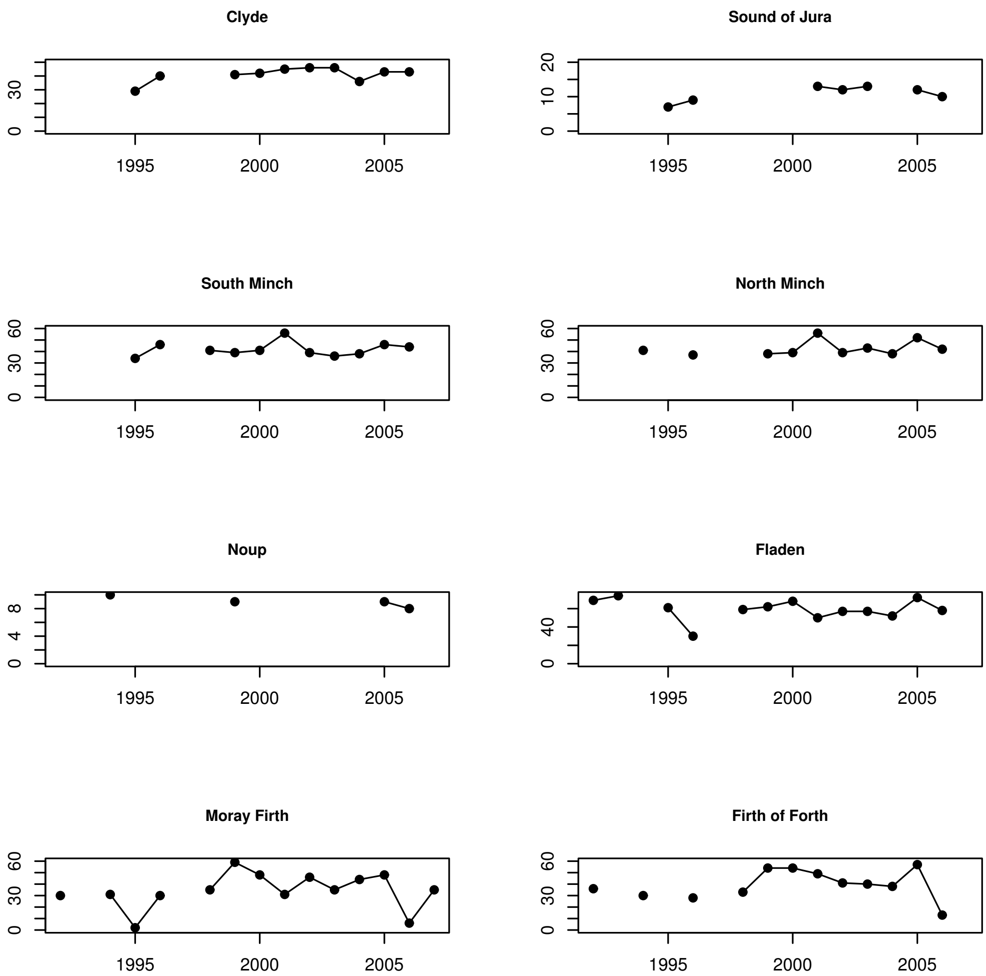


Figure 2. Numbers of successful TV sledge deployments per year in the eight regularly sampled areas. Lines between points denote annual surveys.

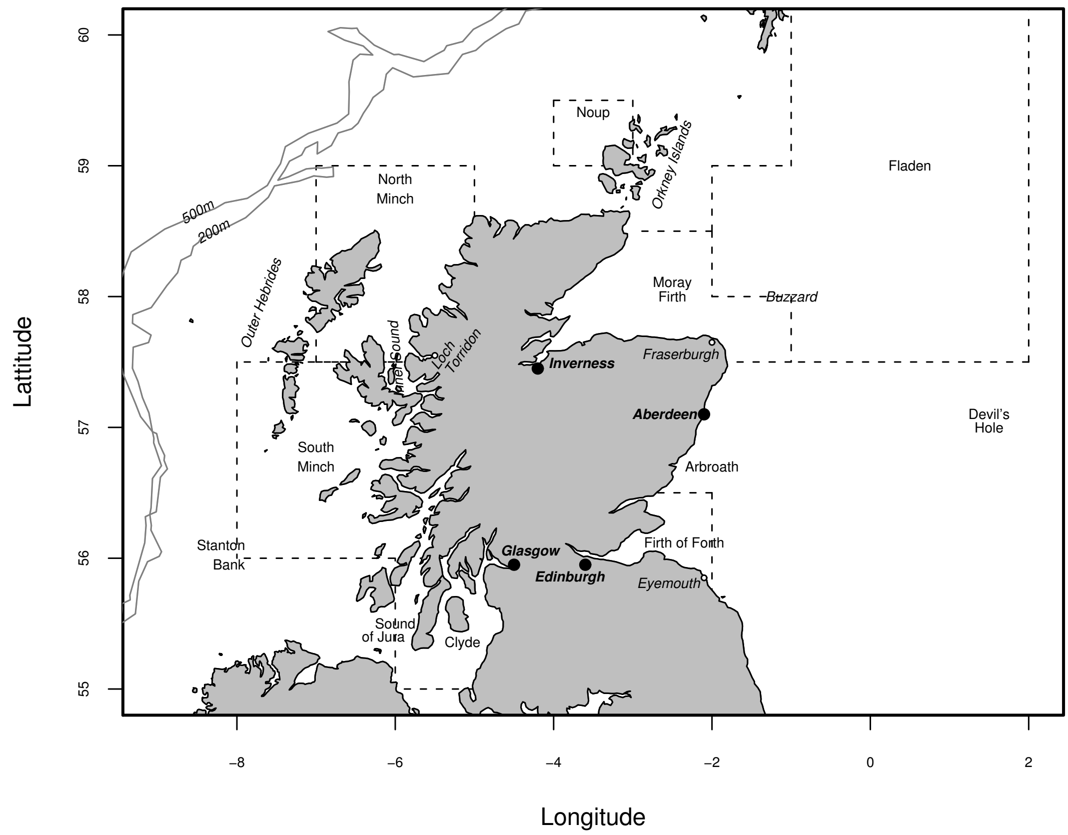


Figure 3. Approximate sites of some locations mentioned in the text.

Because of the number of areas which are surveyed by FRS, the varying nature of the fishery and variable sediment distributions within each, the development of the TV survey has been something of an evolutionary process, and slightly different methods of survey design are applied in each area. These are summarized in table 1. The underlying approach of the FRS TV survey is to adopt a random stratified survey design, and where necessary, subject this randomness to certain fixed geographical limits such that the proportion of samples taken in a strata within a geographic area is directly related to the proportion of the area of that strata in the geographical area to the total area of that strata. This ensures adequate coverage of the whole fished area, to prevent the localized depletion of units within the fishery from going unnoticed.

Firth of Clyde/Sound of Jura

Functional Unit

Functional unit 13, found on the southwest coast of Scotland, contains two recognized areas of *Nephrops* ground, separated by the Kintyre peninsula. To the east, the major area of sediment in the Firth of Clyde, and to the west the smaller Sound of Jura. The functional unit is bounded to the west by the 6°W meridian, to the south and north by the 55°N and 56°N circle of latitude.

Sediment Data

According to the BGS sediment data, functional unit 13 contains 2097 km^2 of muddy sediments (Figure 4). This is divided into muddy sand (668 km^2), sandy mud (708 km^2) and mud (719 km^2). In the Firth of Clyde these sediments occupy the main body of the Firth, to the east and west of the island of Arran, and extending northward, into the Kyle of Bute, Loch Fyne and the Upper Firth of Clyde. Towards the southwest end of the Firth, sediments become progressively sandier, with some sandy gravel and gravels. A small area of slightly gravelly mud is found just outside the functional unit, in the southern end of Loch Ryan, between Cairnryan and Stranraer. This area is the site of an oyster fishery, and not considered suitable for *Nephrops* due to its shallow depth. The Clyde sediments are separated by around 40 km of sand and gravel sediments from the nearest areas of mud in the northern Irish Sea.

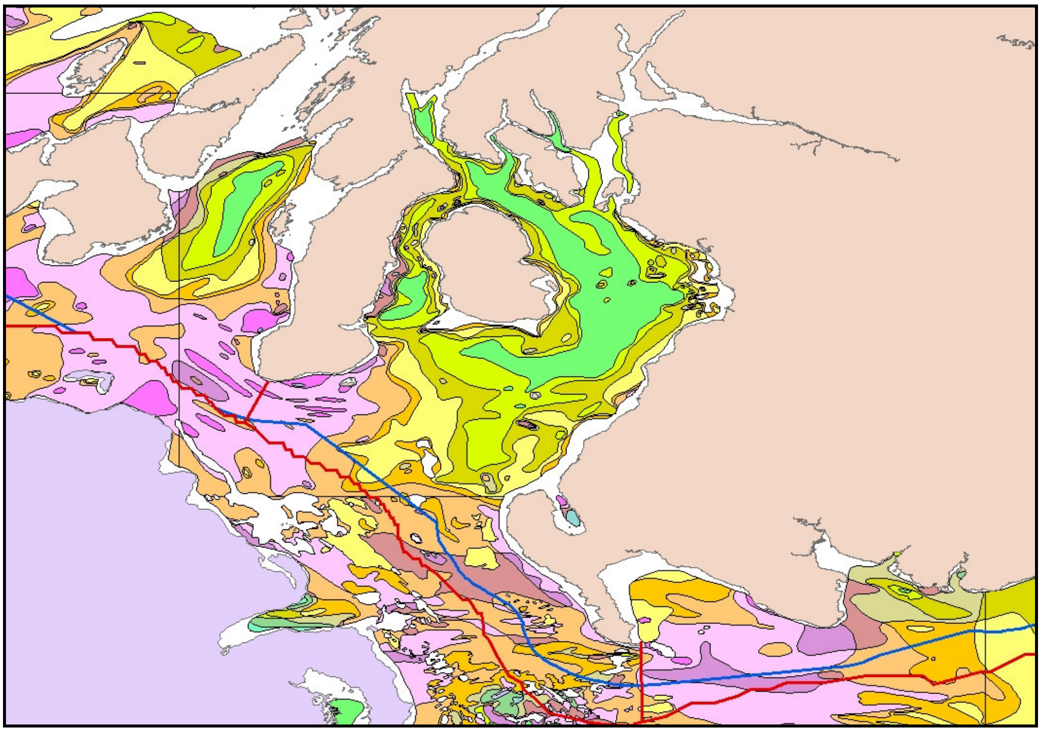


Figure 4. Sediment composition of the Firth of Clyde area.

The Sound of Jura contains a single patch of muddy sediment, bounded to the north by bare rock. This area is relatively close, as the crow flies, to the South Minch functional unit, however poor sediment sampling resolution in this area means this is difficult to quantify.

Stratification

For survey purposes, the Clyde is a random stratified survey, based on the area of the three Folk sediment classification muds (Folk, 1954), divided into northern and southern regions along the 56°30' line. Sampling in the Sound of Jura is stratified into three areas by Folk sediment type without any geographical limitations.

An uninterrupted series of annual underwater TV surveys are available since 1999 for the Firth of Clyde (Figure 2). The numbers of valid stations in the survey have remained relatively stable throughout the time period, in the order of 35–45. The TV survey for the Sound of Jura was not conducted between 1997 and 2000, and also 2004.

South Minch / Stanton Bank

Functional Unit

The South Minch functional unit (FU12) is located off the west coast of Scotland, and is bounded to the north and south by the 56°00' and 57°30' circles of latitude, and to the west by the 8°W meridian. Out with the functional unit, a mixed fishery for gadoids and *Nephrops* takes place on Stanton Bank, to the southwest of the Outer Hebrides.

Sediment Data

BGS survey data shows the South Minch to contain a number of patches of suitable sediments (Figure 5), totalling an area of 5023 km^2. This comprises 2720 km^2 of muddy sand, 2059 km^2 of sandy mud and 244 km^2 of mud. Suitable sediments to the east of Skye are included in the North Minch Functional Unit. A single patch of muddy sediments extends southwards from the southwest coast of Skye to the Ardnamurchan peninsula and westwards to a point around 30 km southwest of Barra. A further patch of muddy sand and sandy mud is found to the west of Mull. Other patches are found in a number of sea-lochs. BGS sampling in this area is not comprehensive, and estimates of sediment area should be taken as minima. A number of small patches of muddy sand and sandy mud are found at Stanton Bank. A further area of muddy sand approximately 80 km to the west of North Uist, although still on the shelf edge, is currently lightly fished.

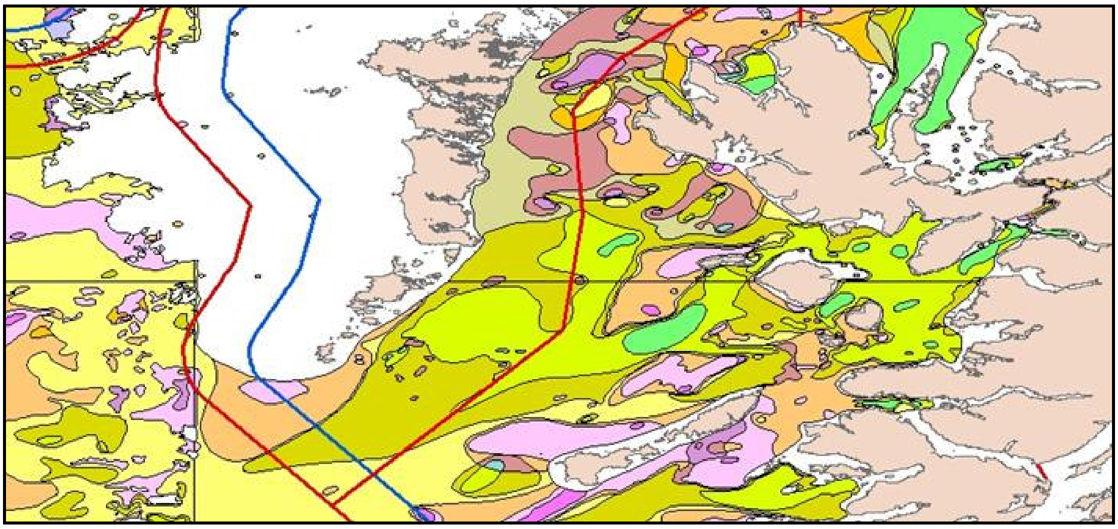
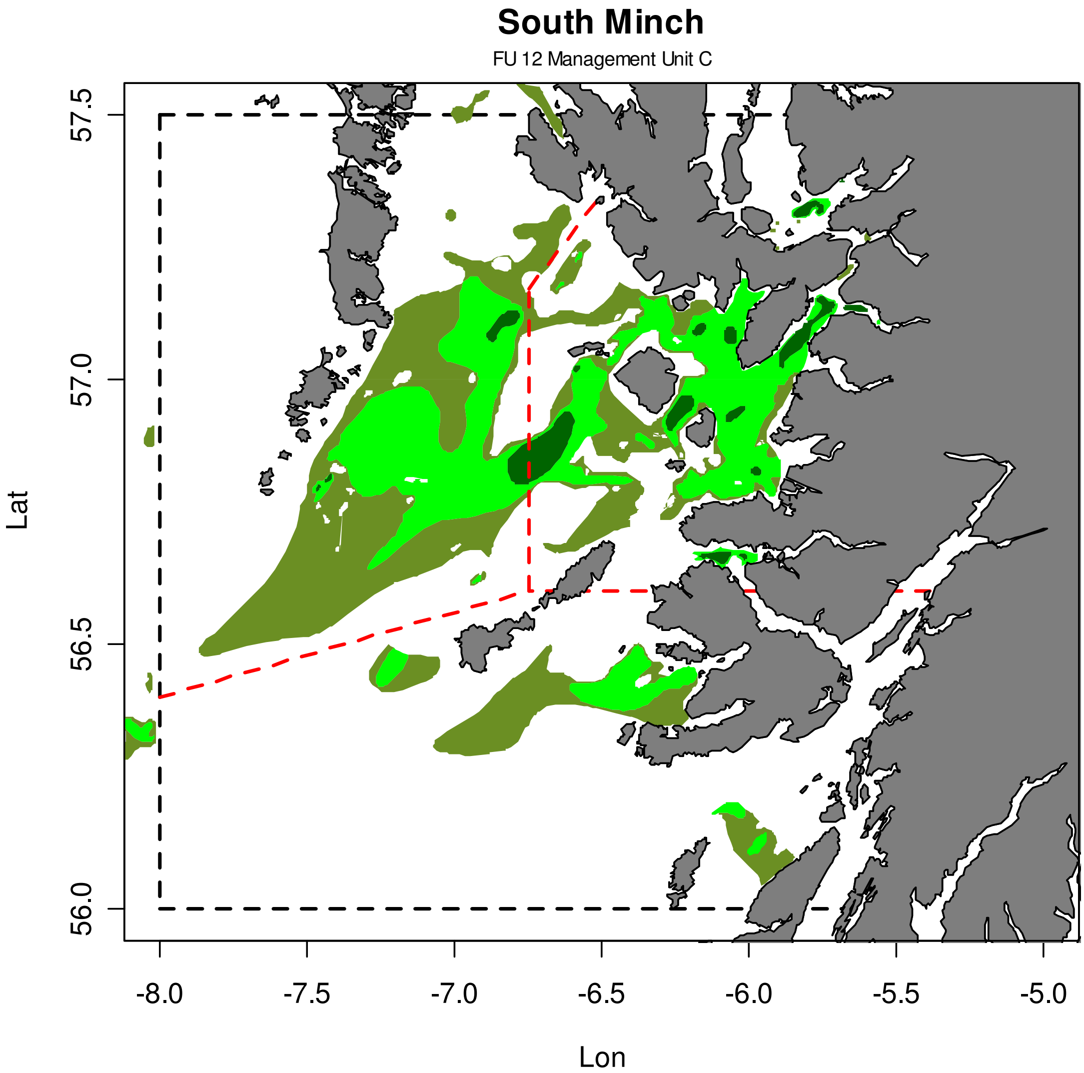


Figure 5. Sediment composition of the South Minch area.

Stratification

The South Minch is sampled randomly, based on three strata, based on Folk sediment type, with a fixed ratio of samples carried out in each of three geographic areas (west, southern and east) and. Sampling at Stanton Bank is carried out at eight fixed positions. The sediment to the west of Uist has not been sampled as part of the regular TV survey, but occasional samples have been taken from this area on the deep-water survey.

An uninterrupted series of data is available from 1998, with approximately 35–50 random stations being examined in each year.



North Minch

<u>Functional Unit</u>

The North Minch Functional Unit (FU 11) is located off the northwest coast of Scotland. The northern boundary of the FU is the 59°N line, although there are no areas of suitable sediment north of 58°30'N. The boundary with the South Minch FU is at 57°30'N. The North Minch includes areas of sediment in the Inner Sound, between Skye and the mainland.

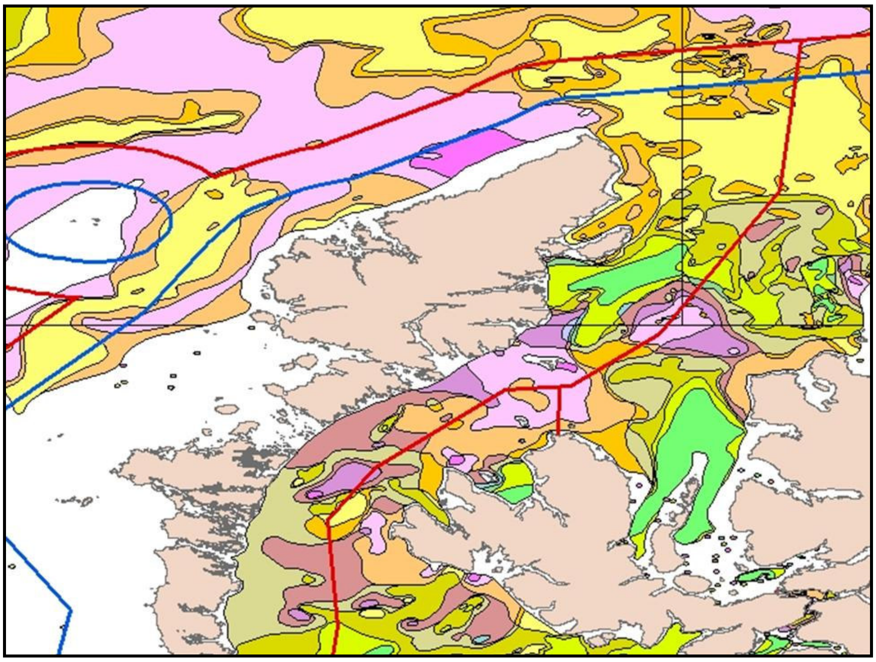


Figure 6. Sediment distribution in the North Minch.

Sediment Data

Again, the resolution of BGS sediment survey data is not ideal in this area – coverage of coastal areas and sea-lochs is poor or lacking altogether. The North Minch as a whole contains 1775 km2 of suitable sediments. These consist of 669 km^2 of muddy sand, 519 km^2 sandy mud and 534 km^2 of mud. A single patch occupies the area between Skye and the mainland, with one "leg" stretching down into the Inner Sound, and the other into the Sound of Raasay. This patch is separated by sandy sediments from a second area, stretching between Lewis and the mainland. This area consists of mud, muddy sand and sandy mud, as well as the slightly gravelly variants of these sediments. Uncertainty exists as to the suitability of these slightly gravelly areas for *Nephrops*, however, anecdotal evidence from the fishing industry suggests that they consider the whole of this area as suitable *Nephrops* ground.

Stratification

Because of this uncertainty in sediment distribution and suitability, the North Minch is divided into four arbitrary rectangles, roughly corresponding to discrete patches of mud in (or on the border of) the functional unit, for survey purposes (Figure 7). Samples are distributed randomly over the area of suitable sediment within each rectangle. In the assessment, burrow densities in the four rectangles are raised to the area of suitable sediment in each region.

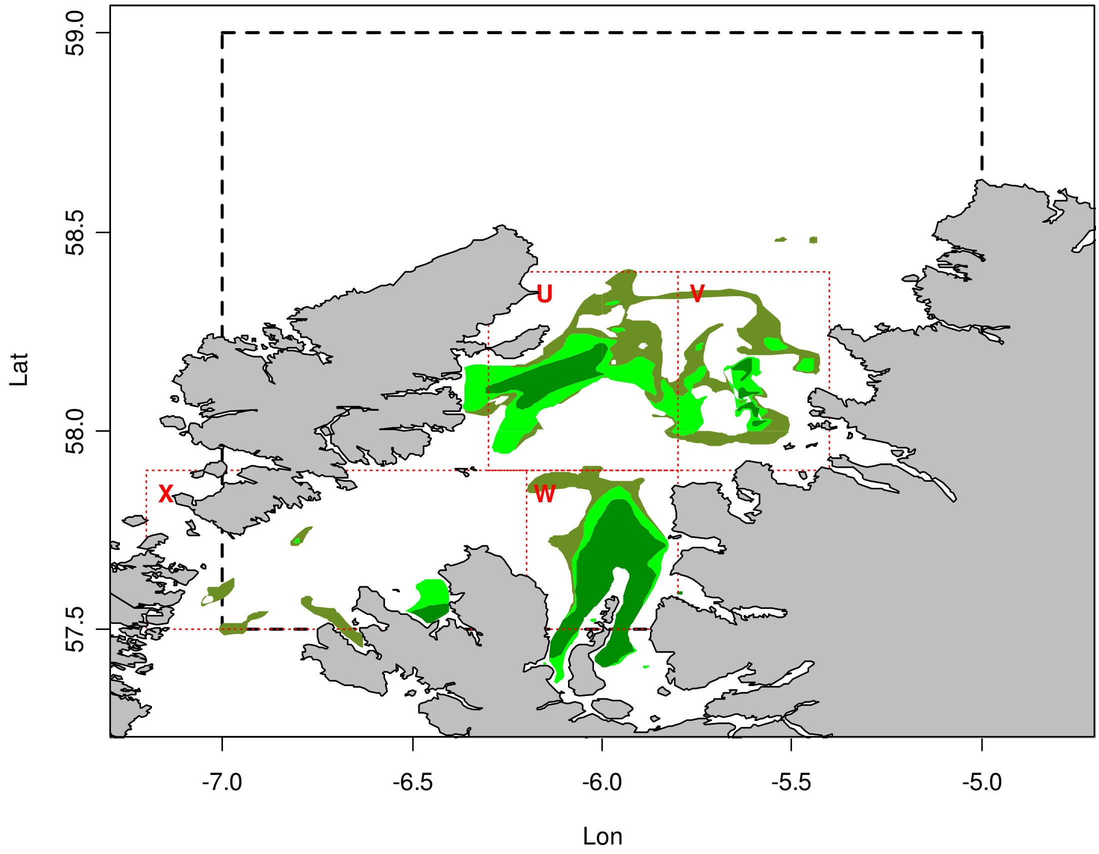


Figure 7. Arbitrary rectangles in the North Minch.

Sampling effort is distributed such that 14–15 stations are surveyed in rectangle U, 9–10 in rectangle V, 10–11 in rectangle W and 4–6 in rectangle X. For assessment purposes, estimates of burrow density in each rectangle are raised to the area of mud, sandy mud and muddy sand in that rectangle and summed to obtain an estimate of the population size in the whole North Minch.

Moray Firth and Noup

Functional Unit

There are two areas of suitable *Nephrops* sediments in Management Area F, the larger in the Moray Firth (FU 9) and the much smaller Noup (FU 10). The Moray Firth is located off the northeast coast of Scotland, and the Noup, to the northwest of the Orkney Islands. The Noup consists of ICES rectangle 47E6, while the Moray Firth consists of rectangles 44E6–8 and 45E6–7.

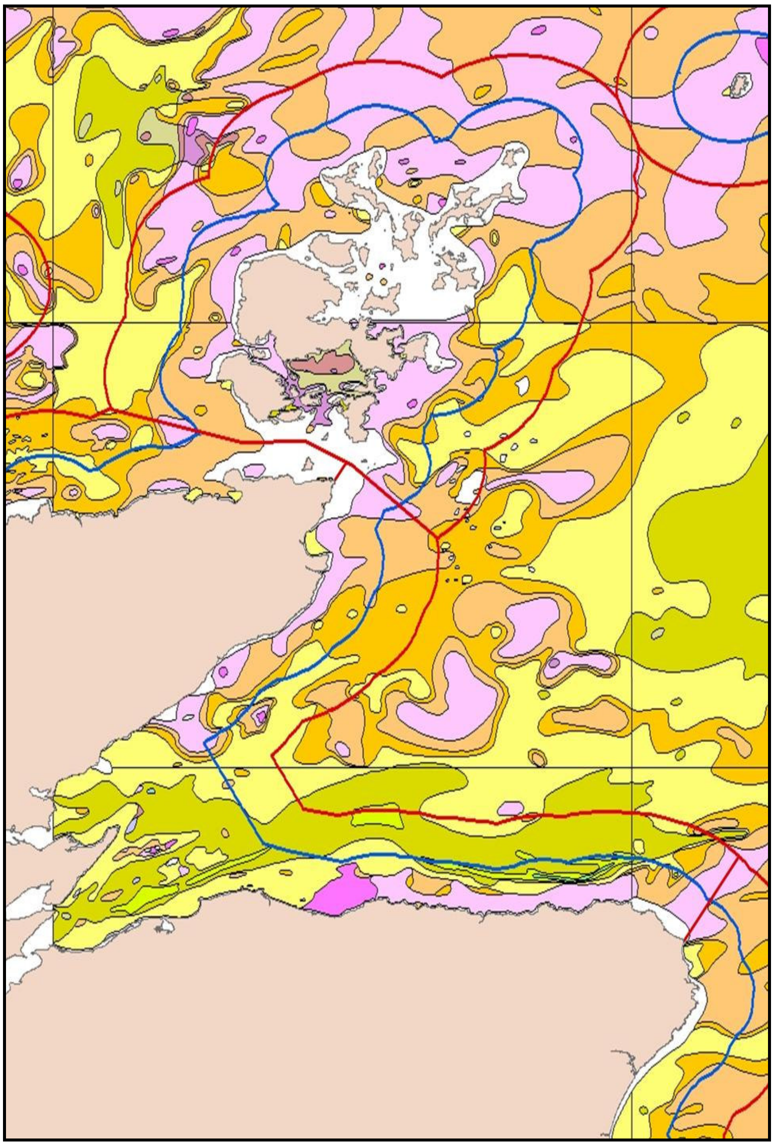


Figure 8. Distribution of sediments in the Noup and Moray Firth.

<u>Sediment Data</u>

Sediments in the Moray Firth and Noup have been surveyed by BGS, and show a good level of sampling, with the only unsampled area being at the far western end of the Moray Firth, near the Kessock channel and Beauly Firth.

The Noup consists of 409 km^2 of muddy sand, while the Moray Firth consists of 2032 km^2 of muddy sand, 191 km^2 of sandy mud, and 12 km^2 of mud. These are distributed in single patches in each functional unit. The muddy sediments in the Moray Firth encircle patches of sandy sediments within the muddy area.

<u>Stratification</u>

The Moray Firth has been sampled more intensely and regularly, with between 30 and 55 stations sampled per year, since 1998 (technical difficulties meant that only 13 stations were sampled in 2006). To ensure adequate spatial coverage, the Moray Firth is divided into three sections – western, central and eastern (Figure 9). Stratification is then by Folk sediment type, with samples randomly distributed within each sediment type.

The Noup (Figure 9b), as a patch of a single sediment type, is sampled randomly. Around 10 stations per survey have been investigated. Sampling effort at the Noup has been sporadic, with surveys taking place in 1994, 1999, 2005 and 2006 (Figure 2).

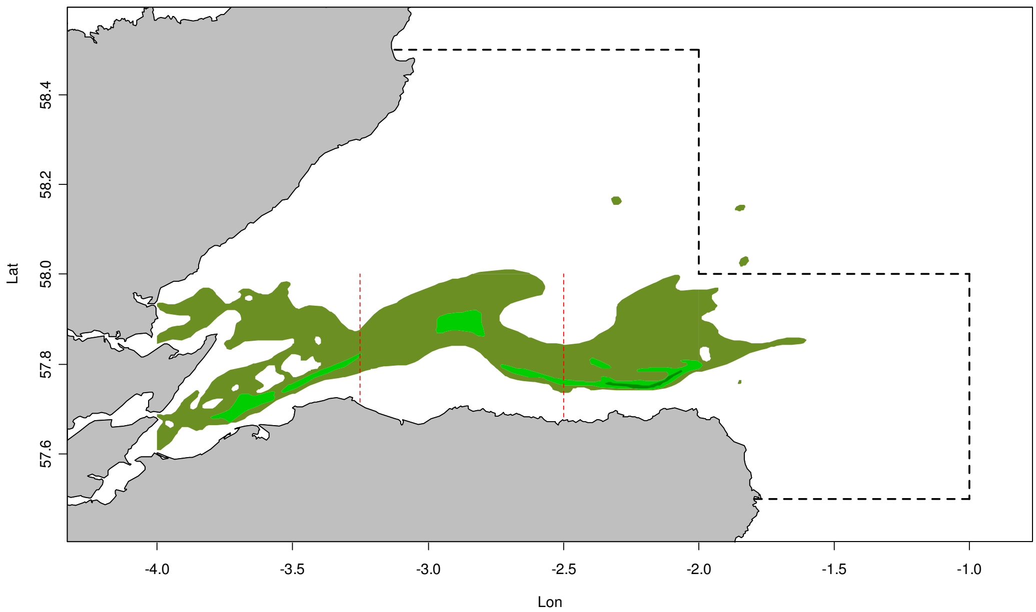


Figure 9. Division of the Moray Firth muddy sediments into three areas, western, central and eastern.

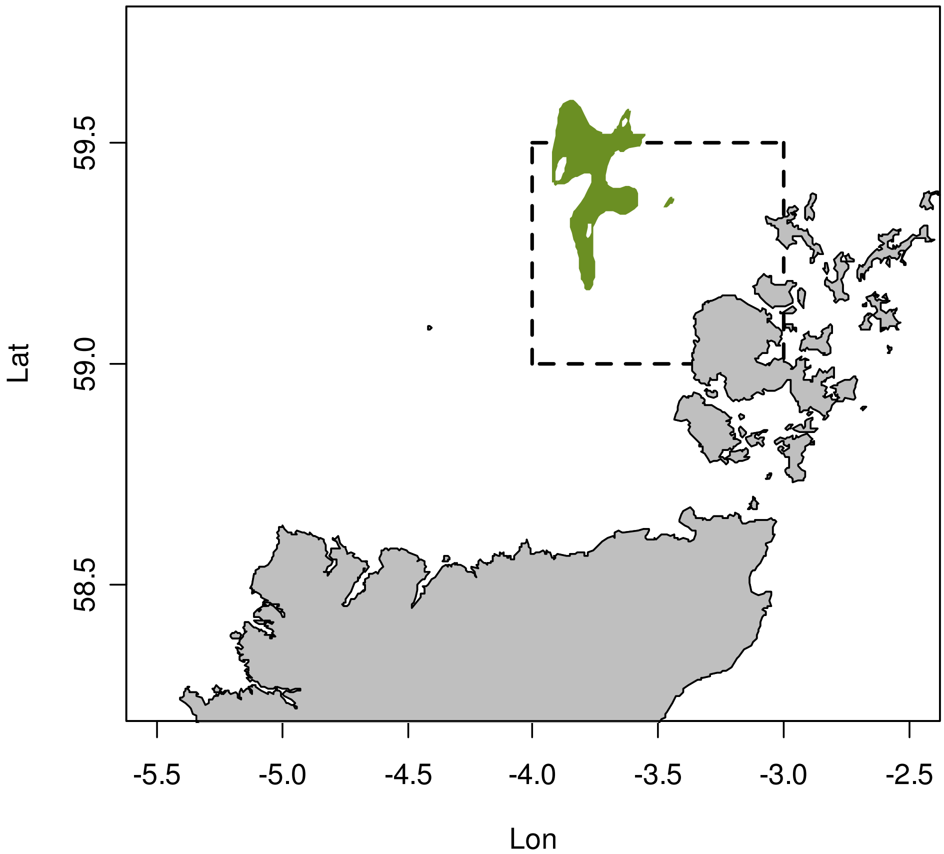


Figure 9b. Functional unit 10, the Noup.

Fladen

Functional Unit

The Fladen (Functional Unit 7) is situated in Management Unit G, off the northeast coast of Scotland from the Moray Firth to the Shetland Islands, and as far east as the 2°E meridian. There are other *Nephrops* populations in management unit G, on muddy sediments to the northwest of the Shetland Islands, over the shelf edge.

Sediment Data

The Fladen is one of the most carefully surveyed areas of sediment off the UK coast, thanks to the oil and gas industry (Figure10). It is the largest area of *Nephrops*-type sediment in Scottish waters, covering approximately 30 000 km^2 of suitable sediment, of which 20 004 km^2 are muddy sands, 9492 km^2 are sandy muds and 1137 km^2 are mud.

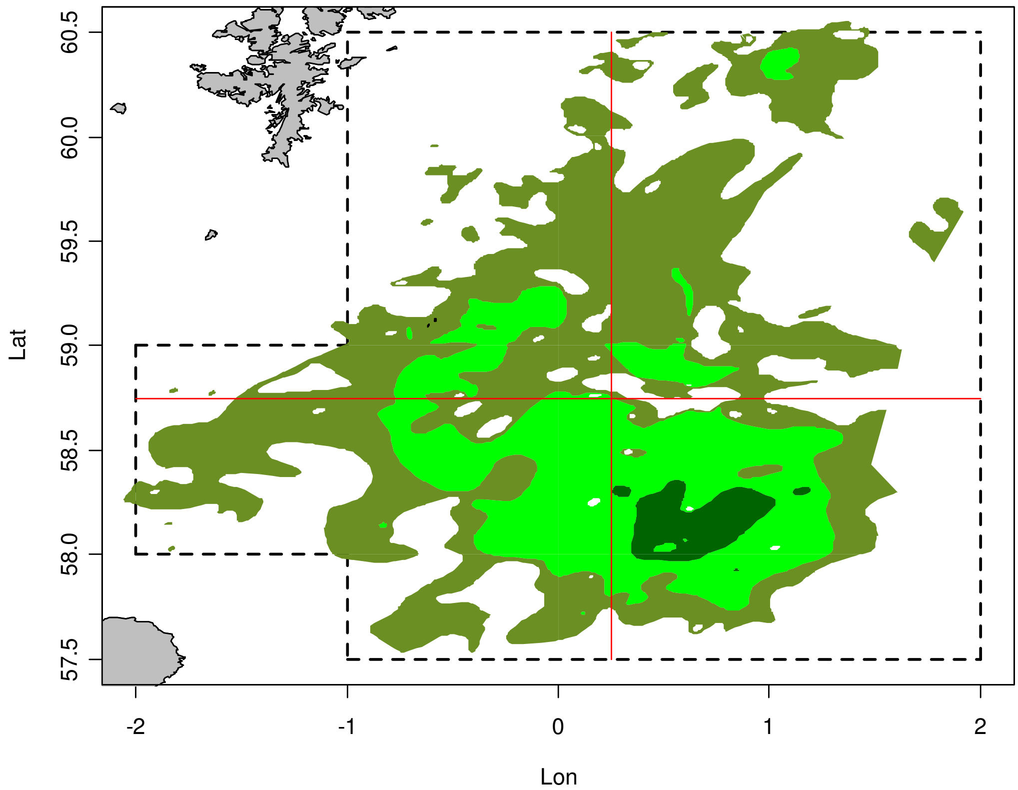


Figure 10. Sediment distribution on the Fladen, survey divisions delineated in red.

Alfonso-Dias (1998) showed that variance in abundance estimates could be minimized by using percentage silt and clay in the sediment, rather than Folk sediment type, as the basis for stratification. Muddy sand and sandy mud cover a wide range of sediment compositions (10–80% silt and clay), and more precise results were obtained by using strata of 10%, 45%, 55% and 80% silt and clay in sediment (Figure 11).

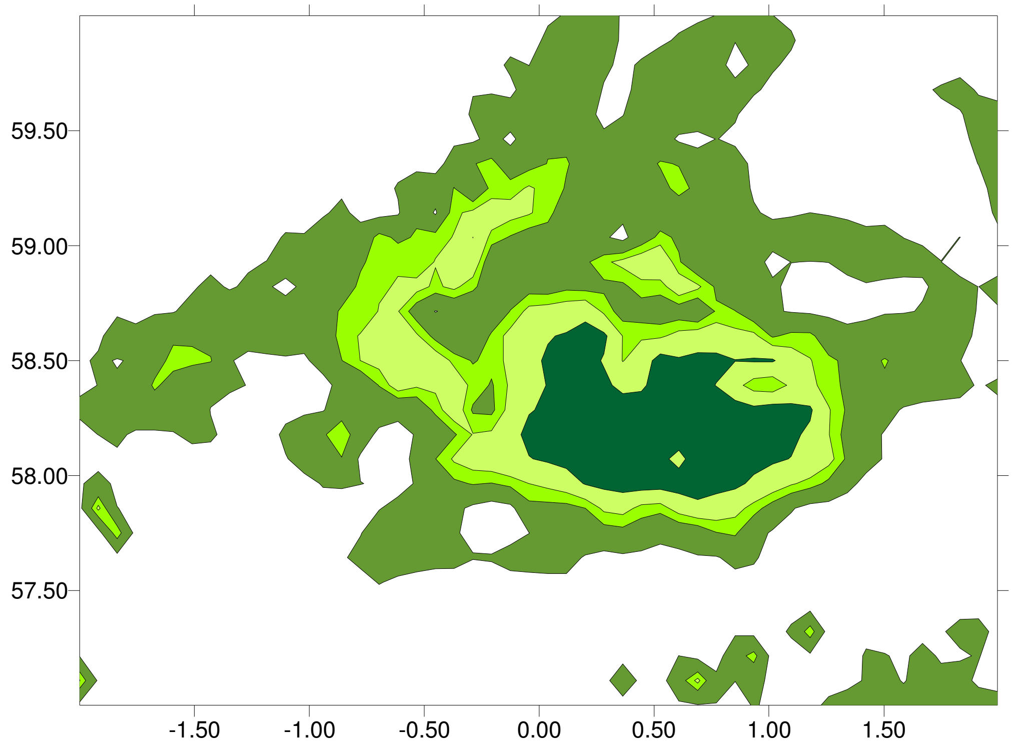


Figure 11. Percentage silt and clay in Fladen sediments.

Samples are distributed randomly within strata, with the proviso that a certain number of samples must be carried out in each of the four quarters of the Fladen (Figure 10, red lines).

The Fladen has been surveyed annually since 1998, with around 50–70 stations per year (Figure 2). Although this is the highest number of stations carried out in a functional unit by FRS, because of the large area of the Fladen, the density of stations appears to be rather low.

Firth of Forth

Functional Unit

The Firth of Forth functional unit (FU 8) is located on the southeast coast of Scotland, and covers ICES rectangles 40E7 and 41E6–7. It is bounded to the east by the 2ºW meridian, and to the north by the 56 º30'N circle of latitude. To the west and south the functional unit is bounded by the Fife and Lothian coastlines. The Firth of Forth shares a border with the Farne Deeps functional unit (FU6) in 40E7.

Sediment Data

Within the functional unit, a contiguous body of suitable sediment (973 km^2), mainly muddy sand (782 km^2) with significant areas of sandy mud (189 km^2) and a very small area of mud (2 km^2), extends from the western limit of BGS sampling, around the Forth Road Bridge, to the near English border, off the coast of Eyemouth (Figure 12). Around 25 km north of the Forth *Nephrops* grounds, off the coast of Arbroath, another patch of suitable sediment is found, consisting of muddy sand with small patches of sandy mud. This patch covers an area of approximately 250 km^2. The Farne Deeps grounds are approximately 70 km to the southeast of the eastern-most end of the Forth grounds.

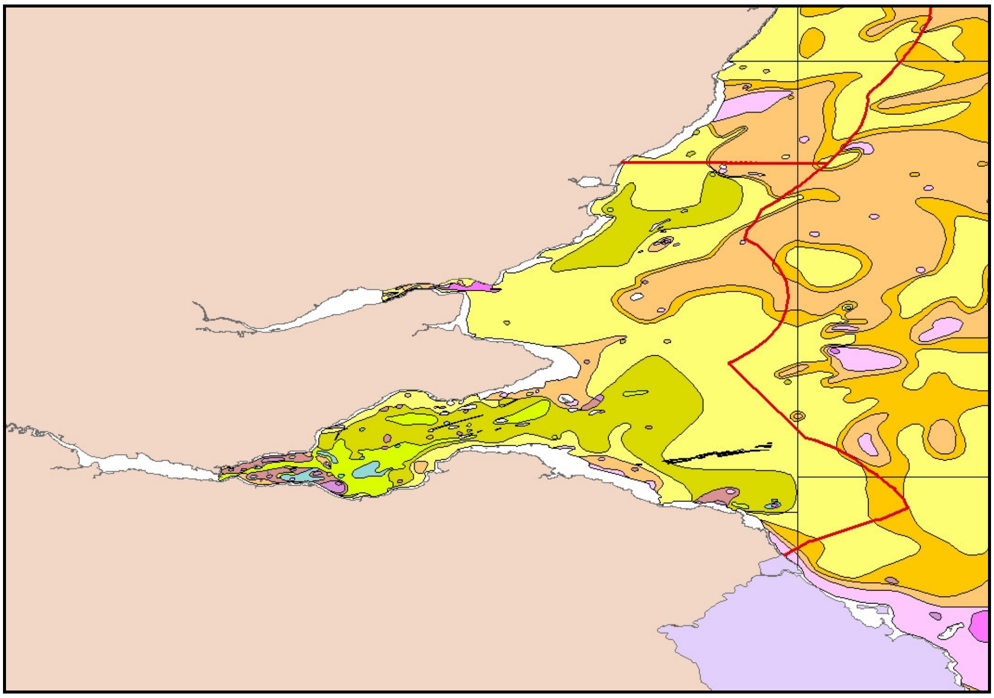


Figure 12. Sediment distribution in the Firth of Forth.

<u>Stratification</u>

The Firth of Forth has been sampled on a regular basis since the instigation of the Scottish TV survey. Sampling has been carried out on RV *Clupea*, mainly in July. Sampling is carried out on a random stratified basis, with samples being randomly distributed in the three sediment strata, subject to the provision that a certain number of samples are located in eastern, central and western portions of the suitable sediment area, defined by the 2°48' and 2°32'W meridians (Figure 13). The area of sediment off Arbroath has not been sampled on a regular basis.

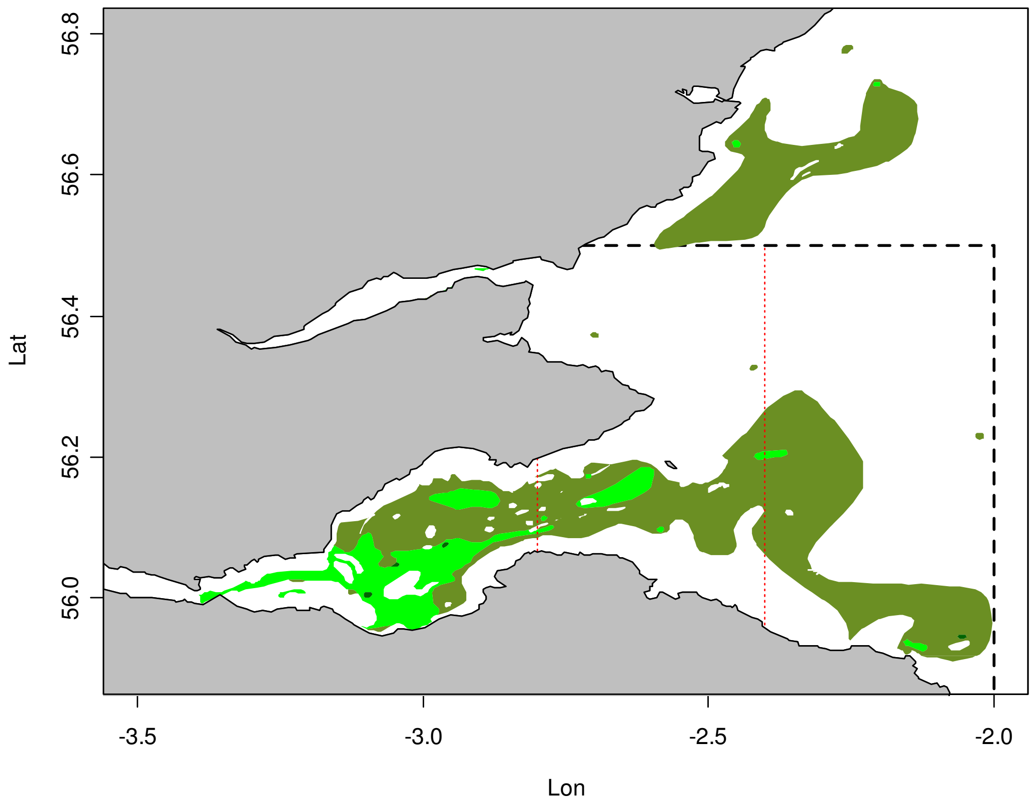


Figure 13. Sediment strata in the Firth of Forth, showing the three segments, delineated by the dashed red lines.

Conclusions

The FRS *Nephrops* TV surveys covers a substantial proportion of the sediments suitable for *Nephrops* burrows in waters around Scotland. The "organic" growth of the survey over the period 1992–2007 is evident from a comparison of the different techniques applied to each functional unit. The survey process could benefit from some rationalisation, such as an analysis of the appropriate level of effort to apply to each FU, and a consistent approach to stratification across FUs. The survey could be extended to cover areas such as the Devil's Hole or Arbroath; however these are not currently included in assessments, and as such are of lower priority.

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BGS (2002) 1: 250 000 Scale Geological Maps of the UK and Continental Shelf Areas (UTM Series).

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Folk, R. J. (1954) The distinction between grain size and mineral composition in sedimentary-rock nomenclature. Journal of Geology **62:** 344: 359.

Howard, F. G. (1982) The Norway Lobster. Scottish Fisheries Information Pamphlet **7** pp. 15.

Table 1. Summary of FRS *Nephrops* TV survey activities.

AREA	FUNCTIONAL UNIT	MANAGEMENT AREA	SURVEY BASIS	STRATIFICATION TYPE	APPRX. STATIONS	NOTES
Arbroath	**n/a**	**I**	**Rarely surveyed**	**-**	**-**	**Low level of landings**
Clyde	**13**	**C**	**Annual (*Scotia*, Q2)**	**Sed. and Geog.**	**40**	
Deep Water	**n/a**	**C/D**	**Annual (*Scotia*, Q3)**	**No**	**-**	**Drop frame**
Devils Hole	**n/a**	**I**	**Occasional (*Scotia*,Q2)**	**No**	**-**	**Overlaps mgt areas I/H**
Firth of Forth	**8**	**I**	**Annual (*Clupea*, Q3)**	**Sed. and Geog.**	**50**	
Fladen	**7**	**G**	**Annual (*Scotia*, Q2)**	**% Clay**	**60**	
Jura	**13**	**C**	**Regular (*Scotia*, Q2)**	**Sediment**	**12**	
Moray Firth	**9**	**F**	**Annual (*Clupea*, Q3)**	**Sed. and Geog.**	**50**	
North Minch	**11**	**C**	**Annual (*Scotia*, Q2)**	**Arbitrary Rect.**	**40**	
Noup	**10**	**F**	**Occasional**	**No**	**10**	**Surveyed in 1994, 1999, 2005 and 2006**
South Minch	**12**	**C**	**Annual (*Scotia*, Q2)**	**Sed. and Geog.**	**40**	
Stanton Bank	**n/a**	**C**	**Annual (*Scotia*, Q2)**	**Fixed stations**	**8**	
West Coast*	**11**	**C**	**Regular (*Clupea*, Q4)**	**Set areas**	**variable**	**Not used in assessment**

West Coast Q4 survey covers a number sea lochs and sounds, and in recent years has focused on the Loch Torridon/Inner Sound area, which is home to a MCS certified *Nephrops* fishery.

Working Document 5

Protocol for Establishing a *Nephrops* Burrow Abundance using Under Water Video.

Weetman and N. Campbell.

Introduction

Since 1992 FRS has carried out under water TV surveys, to provide a method of establishing an index of *Nephrops* burrow abundance. This has been achieved by utilizing a video camera mounted on a towed sledge, with the number of observed *Nephrops* burrow complexes being counted. Based on the assumption that one adult *Nephrops* occupies one burrow complex and that the area surveyed is known, these counts are raised to the known surface area for that strata in that area to produce an estimation of abundance. The method of counting the complexes has changed little over time, but additional information gathered has increased.

Narrative

During the survey, TV stations are surveyed based on a random stratified basis, with a varying number of fixed stations in each area. At each station there are a minimum of two scientists to assist in the launch and recovery of the sledge, operate the winch once the sledge has come in contact with the seabed, and to operate the scientific equipment in the ship's laboratory.

Following a successful deployment of the sledge, the scientific staff took control of the winch operations via a remote control. This allows for an immediate response to any situations that may arise, and which relaying a message to the ship's operators may cause a costly delay or reduce the accuracy of the recording, (for example, seabed obstructions, towing too fast, operating the mini grab, etc). At this point, live pictures of the rear wheel, the winch and the viewing camera are being displayed on three monitors in the Laboratory.

When a valid run is ready to be analysed, there is a sequence that needs to be followed so that all the data are recorded correctly. The first step is to lower the rear wheel and ensure it has full contact with the seabed, and to check the demodulator display is showing an incremental count for distance and a valid reading for camera height off the seabed. The time displayed on the monitor should match that which is being displayed on the logging PC, and that the logging PC and DVD recorder has been set up correctly.

To begin the run the DVD recorder is started first. This should be initiated at least 5 seconds before any further logging equipment is started as it can take this long for the lasers to activate correctly. Following this, the distance value on the odometer and elapsed timer are re-zeroed, and the logging PC is started, all simultaneously.

At the beginning of a live run, several variables are recorded manually on a preformatted sheet. This provides as a cross reference to the logged data and as a back up to the electronic copy in case these files are corrupted. It also allows for additional anecdotal remarks to be noted as the run is recorded. At the end of the run, the number of *Nephrops* burrow complexes, *Nephrops* in their burrows and *Nephrops* out of their burrows are recorded. (This value is provisional, as the operator can be distracted by ship's operations and checking the equipment is recording correctly, for example. The value is also representative of the full ten minute run, unlike the verified count, which are noted at one minute intervals). The DVD recorder is stopped a few seconds after the run has finished and the logging PC has been stopped.

At this point the wheel is raised, more cable is paid out to counteract the forward motion of the vessel, (so that the sledge stops travelling forward), and the van Veen grab can be released.

After collecting a sediment sample, the grab is recovered, and the sledge is returned to the ship.

These live counts can provide a basis for an adaptive survey if this technique is to be employed on the survey. Yet the counts used for assessment purposes are recorded at a later date. These ‘verified’ complex counts are based on the same principles as the live counts but they are performed in a slightly different way.

Before verifying burrows, the scientists need to be confident in their observation and identification skills. Using clear, slow runs, training sessions are provided for those new to the task, and act as refresher courses for those requiring reminding.

Away from the main working environment, scientists review video runs alone (see Figure 2). Mechanically tally counters are used to register counts, but on each depression these units make a noise that can be distracting and influence observers if working in pairs.

The ten minute recording is broken down in to 1 minute sections. This allows for greater manipulation of the data and a clearer picture of the changes over the length of the run.

Complexes are only counted if they pass over the bottom of the monitor screen, which has a known width of view (being 1 m when the sledge is lying horizontally on the seabed surface). Any burrows that are in view at the top of the screen but are seen to go out of view at the edges of the monitor (due to the camera being angled obliquely producing a trapezoid picture), are not counted. Observers must be able to distinguish between one multi-entranced burrow and several separate more simple complexes. Essentially, if the observer is not entirely sure of a complex, it is not recorded, thus providing a safer underestimation index.

In addition to burrows, observers are asked to record, per minute, the number of *Nephrops* within burrow entrances and on the seabed. Only *Nephrops* that would originally be in the field of view and unaffected by the sledge should be counted. Therefore, a startled *Nephrops* that reacts to the sledge and swims from the centre of the screen off the side would be counted, and conversely, a *Nephrops* that swims into view would be ignored. The same principle is used for *Nephrops* in burrows, in that if the animal was originally on the surface yet reacts to the sledge and heads for a burrow, it is recorded as ‘out’. Similarly to burrows, that if a *Nephrops* is stationary yet the trapezoid effect means that it goes out of view at the side of the monitor, it is not counted. It is only observations that cross the bottom of the monitor screen that are included.

The oblique camera provides a view that allows time to consider objects when they come in to sight at the top of the screen before they are counted or dismissed by the time they reach the bottom of the screen. This is an advantage in difficult conditions (poor visibility, dense burrows, or areas where there are many other species burrowing). This extra time can also be used to make general recordings of other observations. In the past, interest in sea pen populations have been expressed, and the verified recording sheet reflects this with ‘check boxes’ to comment on the abundance of three species; Pennatula phosphorea, Funiculina quadrangularis and Virgularia mirabilis. A key to grade the abundance is available to the observer (see Figure 1) but this should be applied to the whole 10 minute run, and not each minute, as this would become a distraction from the primary objective of burrow counting. This approach is applied to all the additional notes, to the point where it maybe the case where there are too many burrows or the interpretation requires so much concentration that a run may have to be repeatedly reviewed to take further notes. It is made very clear that although there are check boxes to prompt for additional information (gadoids, flatfish, other species of life and trawl marks), these notes should not be at the expense of accurate burrow counts.

Standardization is essential be it burrow counts, sea pen observations or clarity. To this effect, a key has been devised that each observer should adhere to (see Fig 1.). When studying observer variability data, it became clear that individuals’ interpretation of water clarity was highly subjective, and if there had been consistency among observers, the results would have been more robust.

At present this additional data has yet to be utilized in any formal way. However, there are plans to use the Ground Type description to avoid rocky sites in the future; and to produce a time-series map of sea pen distribution and their species-specific abundance, and noting trawling areas.

When a run is being conducted, the sledge does not always remain in contact with the seabed (labelled ‘lifting’, or off the seabed for a sustained period of time, ‘flying’), then additional minutes maybe added to the end of the standard ten minute run. The verified sheets take this into account but also provide a check box to note in which minute there was no visibility due to flying, lifting or disturbed sediment.

It is important that observers record not only the number of seconds where no counting was possible, but the actual time (going by the elapsed timer). This information is used if the count for the successful section of the run is raised to the whole minute.

At the end of verifying a run, and all the data has been recorded, the observer initials the verified sheet (containing the observations) and a check sheet (which has a list of all the runs recorded), so that a single run is not reviewed more than twice, unless there is a good reason to do so.

The verified counts, occupied burrows and counts of *Nephrops* out of the burrows are added to a standardized spread sheet that can directly interrogated by the work up programme.

Sea pen Abundance Key.

R	-	Rare	Just a few (1–5) over the 10 minute run.
O	-	Occasional	A handful over the 10 minute run (a couple of dozen).
C	-	Common	Observed all the time, every few minutes.
A	-	Abundant	In almost all frames, multiples in frames.

Use combinations like O – C.

Visibility Key.

E	-	Excellent	Crystal clear (e.g. Deepwater, no suspended particles).
G	-	Good	Seabed easily observed, small amounts of suspended matter but this does not affect the visibility.
P	-	Poor	Suspended matter, dense fauna or disturbed sediment results in a partially obscured view of the seabed. Burrows can be seen but uncertainty if all burrows have been accounted for.
VP	-	Very poor	Suspended matter, dense fauna or disturbed sediment is present in such volume that only unidentifiable shadows can be seen on the screen, resulting in uncertain estimations.
Z	-	Zero	for whatever reason (sledge flying, sediment disturbance, dense gathering of fauna, effects of trawling, etc) there is no view of the seabed at all. No counts can be provided in this case.

Figure 1. Grading key

RUN No.	DATE	TIME	AREA

ID:	BURROW	*NEPHROPS*		ID:	BURROW	*NEPHROPS*		SECS NOT
Min	COUNT	in	out	Min	COUNT	in	out	COUNTED
1				1				
2				2				
3				3				
4				4				
5				5				
6				6				
7				7				
8				8				
9				9				
10				10				
11				11				
12				12				
13				13				
14				14				

NOTES

GROUND	VISUAL		FISH			SEA PENS*		OTHER**	TRAWL
TYPE	CLARITY	Gadoids	Flats	Others	Pen.	Fun.	Vir.	LIFE	MARKS

Figure 2. Verified count sheet

FRS Burrow Density Calculations

FRS calculates burrow densities using purpose written software routines. These have recently been converted from Fortran to R (see appendix I), allowing greater integration with our sediment mapping codes.

These routines require the input of a working directory, in which to look for and write files, and the name of an index file, which contains details of the sledge set-up and the names of the files which contain the verified counts and logged data taken from the sledge.

Index File

The index file is a text file which contains details of the survey, such as area surveyed and physical parameters of the sledge, as well as a list of the count and data files to read in.

0805S	-	Survey code
FL	-	Area code (Fladen)
90 108 9223.557.62 43.60	-	Camera parameters
72	-	No. sites in file
FL05001.dat	-	Logged data file 1
FL05001.txt	-	Verified count file 1
FL05002.dat		
FL05002.txt		
FL05003.dat		
FL05003.txt		
(Etc.)		

The sledge parameters are, respectively, height of the front of the camera, height of the rear of the camera, height of the rangefinder and length of the camera, all in centimetres, followed by vertical and horizontal fields of view of the camera, in degrees. The code then reads and loads each pair of count and data files, as given in the index.

Verified Count Files

The burrow counts for each observer are collated in a single spreadsheet, together with comments regarding the visibility in each minute of the run. Where there is no visibility for a portion of a minute and the sledge is moving (as indicated in the logged data file) the burrow count is raised to a whole minute. Where there is no visibility in a minute of the run, a “NA” is entered, which allows the code to discount that minute when calculating densities.

The finalized spreadsheet is then condensed to a single text file with four columns, giving the identification number for each run, the minute of the run and the burrow count for each observer. An additional piece of code then takes this text file and creates an individual file for each run.

The format of the count files is as follows:

11			-	No. of lines to read in		
0 0			-	2 mystery zeroes (FORTRAN legacy code?)		
1	0	0	-	Minute 1	Count 1.1	Count 2.1
2	2	2	-	Minute 2	Count 1.2	Count 2.2
3	4	4	-	Minute 3	Count 1.3	Count 2.3
4	2	1 (etc.)				

Logged Data Files

The data from the sledge, such as depth, range off the bottom and distance covered are combined with positional data from the ship or from a Garmin GPS unit and fed into a pc, which logs the data to a file, and prints a hard copy for reference in case of data loss.

The data are logged in the following structure:

fl05001	-	Site ID Code
04/06/05	-	Date

195130, 0, 57.916, -0.502, 117.6, 0.98, 0

195140, 10, 57.917, -0.502, 117.7, 1.13, 0

195145, 15, 57.917, -0.502, 117.6, 1.15, 2

195150, 20, 57.917, -0.502, 117.6, 1.16, 3

195155, 25, 57.917, -0.502, 117.5, 1.18, 5

(etc.)

cumulative time, run time, latitude, longitude, depth, height of rangefinder, distance covered

In event of the failure of the rangefinder or “3 in 1”, or when using the drop frame, additional code is used to generate distance from logged position or to simulate range data.

Work-up Code

The R code used to calculate densities is given in appendix I. This code has been annotated (text marked out with a hash) to explain the processes involved.

To summarize very briefly, the logged data and counts for each site are read in, the sledge parameters are then used to calculate an average width viewed for each minute of the run, and this is multiplied by the distance covered in each minute to give the area viewed. The burrow counts are then divided by the area to give a value for density.

This code also automatically generates diagnostic plots to identify any problems in the data which is being used. Figure 3 shows an example from the Inner Sound. The sledge begins to lift off the bottom around 4 minutes into the run, at which time burrow counts drop. As the range stabilizes, higher counts return.

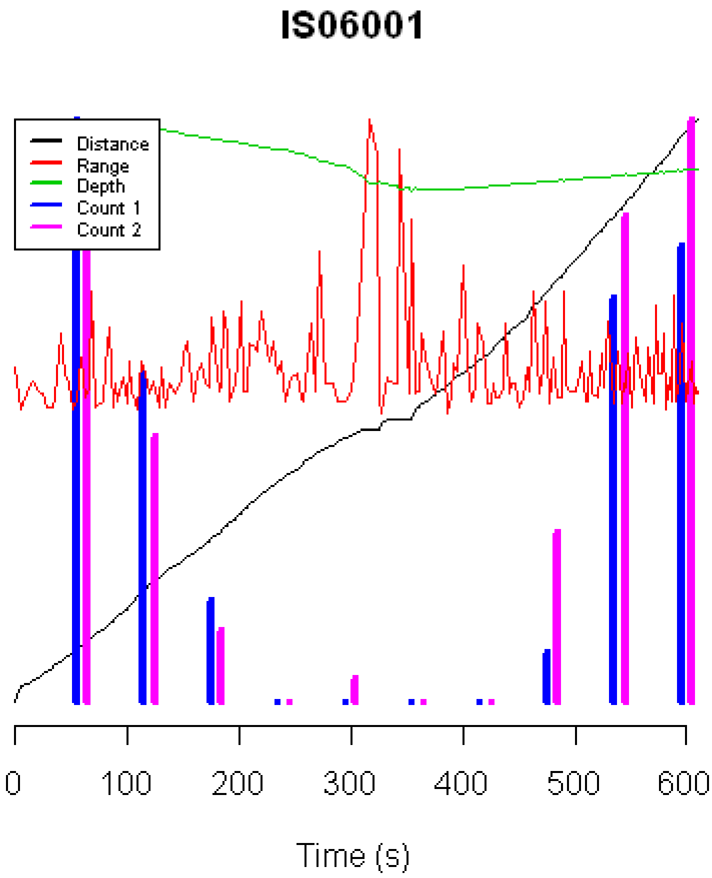

Figure 3 Diagnostic plot generated by TV workup code.

Appendix I – TV Workup code in R

```
##########################

## ##

## TV Density Work-up ##

## ##

##############nc#17.3.07##

tv.workup <- function(working.dir, index.file){

## sets up function

file.list <- readLines(paste(working.dir, index.file, sep="/" ))

## reads in index file

cruise <- file.list[1]

functional.unit <- file.list[2]

front.height <- as.numeric(strsplit(file.list[3],

 split=",")[[1]][1])

back.height <- as.numeric(strsplit(file.list[3],

 split=",")[[1]][2])
```

```
rangefinder.height <- as.numeric(strsplit(file.list[3],
 split=",")[[1]][3])
camera.length <- as.numeric(strsplit(file.list[3],
 split=",")[[1]][4])
horizontal.angle <- as.numeric(strsplit(file.list[3],
 split=",")[[1]][5])
vertical.angle <- as.numeric(strsplit(file.list[3],
 split=",")[[1]][6])
camera.angle <- acos((back.height - front.height)/
 camera.length)*(180/pi)
height.differential <- (front.height-rangefinder.height)/100
lower.edge.view <- camera.angle-(0.5*vertical.angle)
no.stations <- as.numeric(file.list[4])
## reads in sledge parameters from the index file header
file.list <- file.list[5:length(file.list)]
file.list <- file.list[file.list!=""]
if(is.na(cruise)){
print("There are problems with your index file - please check it is
 of standard format and try again")
break
}
if(sum(is.na(c(front.height, back.height, rangefinder.height,
 camera.length, horizontal.angle, vertical.angle, camera.angle,
 height.differential, no.stations)))>0){
 print("The values for sledge parameters have not been correctly
 formatted, check your file and try again")
 break
}
if (length(file.list)==2*no.stations){
 print("CORRECT NUMBER OF FILES IN INDEX")
}
if (length(file.list)!=2*no.stations){
 print("INCORRECT NUMBER OF FILES IN INDEX")
 break
}
```

```
## some quality control checks

lats <- vector(length=length(file.list)/2)

lons <- vector(length=length(file.list)/2)

average.densities <- vector(length=length(file.list)/2)

counter.1.densities <- vector(length=length(file.list)/2)

counter.2.densities <- vector(length=length(file.list)/2)

## sets up vectors to hold outputs

if(file.exists (paste(working.dir, "Diagnostic Plots", sep="/")) !=

 TRUE) {

 dir.create(paste(working.dir, "Diagnostic Plots", sep="/"))

}

## checks to see if directory exists, and if not, creates one

for (i in (1:(length(file.list)/2))){

 pos.file <- read.table(paste(working.dir, file.list[(i*2)-1],

 sep="/"), skip=2, header=F)


 if (dim(pos.file)[2] > 7 | dim(pos.file)[2] < 7){

 pos.file <- read.csv(paste(working.dir, file.list[(i*2)-1],

 sep="/"), skip=2, header=F)

 }


 count.file <- read.table(paste(working.dir, file.list[(i*2)], sep="/"), skip=2)

 ## checks if data file is tab or coma delimited and

 ## reads in each count file and corresponding DAT file

if(sum(pos.file[,6]<3)>0){

pos.file[,6][pos.file[,6]>3] <- mean(pos.file[,6][pos.file[,6]<3],

 na.rm=T)

}

## replaces range when sledge is “flying” with average range when

## it is on the bottom (these seconds are discarded and counts

## raised to a whole minute already)

if(sum(pos.file[,6]<3)<1){

pos.file[,6] <- rep(0.88, dim(pos.file)[1])

}

## sets an arbitraty range if the rangefinder was not functioning,
```

```
## allowing for 4 cm penetration of the sledge into the seabed
lats[i] <- pos.file[13]
lons[i] <- pos.file[14]
## reads start lat and lon (ok to assume 10 min runs are a point)
png(filename =paste(working.dir, "/Diagnostic Plots/",
 strsplit(file.list[(2*i)-1], split="\\.")[[1]][1], ".png", sep=""),
 width = 480, height = 480, pointsize = 12, bg = "white", res = NA,
 restoreConsole = TRUE)
plot(pos.file[,7]/max(pos.file[,7])~pos.file[,2], ylim=c(01),
 type="l", xlab= "Time (s)", ylab="", yaxt="n", bty="n",
 main=strsplit(file.list[(2*i)-1], split="\\.")[[1]][1])
for(j in (1:dim(count.file)[1])){
lines(x=c((count.file[j,1]*60)-5, (count.file[j,1]*60)-5),
 y=c(0,count.file[j,2]/max(count.file[,2],na.rm=T)), lwd=4, col=4)
lines(x=c((count.file[j,1]*60)+5, (count.file[j,1]*60)+5),
 y=c(0,count.file[j,3]/max(count.file[,3], na.rm=T)), lwd=4, col=6)
}
lines(x=pos.file[,2], y=pos.file[,6]/max(pos.file[,6], na.rm=T),
 col=2)
lines(x=pos.file[,2], y=pos.file[,5]/max(pos.file[,5], na.rm=T),
 col=3)
legend(x=0, y=1, legend=c("Distance", "Range","Depth","Count 1",
 "Count 2"), col=c(12 346), lwd=2, cex=0.6)
dev.off()
## produces a folder of diagnostic plots to help track problems
colnames(count.file)<-c("Mins", "C1", "C2")
minutes <- dim(count.file)[1]
distance.covered <- vector(length=minutes)
mean.count <- vector(length=minutes)
view.width <- vector(length=minutes)
average.height <- vector(length=minutes)
if (pos.file[17]<30){
start.dist <- pos.file[17]
 }
```

```
if (pos.file[17]>30){

start.dist <- 0

 }

for (x in (1:minutes)){

temp.mat <- pos.file[pos.file[,2]<=count.file[x,1]*60 and

 pos.file[,2]>=(count.file[x,1]-1)*60,]

## creates matrix of data which lies in the appropriate minute

distance.covered[x] <- temp.mat[dim(temp.mat)[1],7] - start.dist

average.height[x] <- mean(temp.mat[,6] - height.differential)

## works out distance covered and average height of sledge

view.width[x] <- 2 * (average.height[x]/cos(lower.edge.view*(pi/180)))*tan(0.5*

 horizontal.angle*(pi/180))

## calculates view width for that minute

start.dist <- temp.mat[dim(temp.mat)[1],7]

}

area <- view.width * distance.covered

## produces vector of area viewed in each minute of the run

density.1 <- count.file[,2]/area

density.2 <- count.file[,3]/area

average.density <- ((sum(count.file[,2],na.rm=T)+sum(count.file[,3],

 na.rm=T))/2)/sum(area, na.rm=T)

## calculates densities

average.densities[i] <- average.density

counter.1.densities[i] <- mean(density.1, na.rm=T)

counter.2.densities[i] <- mean(density.2, na.rm=T)

}

return.list <- list(lats=lats, lons=lons, average.density=round(average.densities, 2),
count.1=round(counter.1.densities,2), count.2=round(counter.2.densities, 2))

return(return.list)

## rounds up values and returns them as a list

}

## call the function as…

# tv.workup ("C:/Work/TV/Noup", "INDEX. TXT") -> noup.dens

# tv.workup ("C:/Work/TV/North Minch", "INDEX. TXT") -> nm.dens

# tv.workup ("C:/Work/TV/South Minch", "INDEX. TXT") -> sm.dens
```

```
# tv.workup ("C:/Work/TV/Sound of Jura", "INDEX. TXT") -> sj.dens

# tv.workup ("C:/Work/TV/Fladen", "INDEX. TXT") -> fl.dens

# tv.workup ("C:/Work/TV/Clyde", "INDEX. TXT") -> cl.dens

# tv.workup ("C:/Work/TV/Moray Firth", "INDEX. TXT") -> mf.dens

# tv.workup ("C:/Work/TV/Firth of Forth", "INDEX. TXT")-> ff.dens
```

Working Document 6

Deriving appropriate harvest rates for the *Nephrops* stocks around Scotland

Helen Dobby, FRS Marine Laboratory, Aberdeen.

Introduction

A wide range of different methods have been used for the assessment of *Nephrops* stocks in recent years. Historically, assessments made use of commercial length composition data in length cohort analysis (LCA, Jones 1979 and 1984). These methods provided information on the state of the stock assuming equilibrium conditions, but no information on stock trends. Additionally, such analysis can result in incorrect fishing mortality estimates, particularly when there has been a systematic trend in the actual fishing mortality. As a result of these concerns and the need for short and medium term stock projections, alternative approaches were investigated. At more recent *Nephrops* Working Groups the length composition data have been sliced into age groups to produce catch-at-age data which were then used with Extended Survivors Analysis (XSA). Von Bertalanffy growth parameters are used to generate 'slicing points' in the length distributions and these divide the data into so-called 'age classes'. Predictions of future catches were then made based on recent landings adjusted in proportion to the estimated change in stock size. Such methods clearly place great reliance on reliable catch data. In recent years, the poor quality of the official landings data has led the WGs to conclude that such catch based assessments are, for the time being, likely to be unreliable, although the introduction of the Registration of Buyers and Sellers legislation is likely to improve official data in the future.

For a number of years now, FRS has carried out annual stratified-random underwater TV surveys (Bailey *et.al.*, 1993; Marrs *et.al.*, 1996) which have been used to estimate *Nephrops* abundance, based on counts of burrows. The sledge is towed for a known distance and the number of burrows counted in a known field of view. Making the assumption of 1: 1 burrow occupancy, the density of *Nephrops* can be calculated and this is then raised to the total area to give an abundance estimate in terms of total number of individuals. Surveys began in 1992 at the Fladen and have since been extended to cover all the major stocks around Scotland.

In 2005 and 2006, ACFM agreed with the assessment WGs (WGNSDS and WGNSSK) that the TV survey results provided the best indications of stock status and concluded that the stocks off the Scottish coast currently appeared to be exploited at a sustainable level. For these stocks, they advised that the catches should be set at a level that did not allow for an increase in effort and that the fishery must be accompanied by mandatory programmes to collect catch and effort data on both target and by-catch species. However, the provision of catch options in accord with this advice has proved somewhat troublesome.

Basis for 2005 and 2006 advice (as I understand it)

Over a number of years at WGNEPH (ICES, 1998, 1999), a method of providing advice on catches from the TV survey data was developed following concerns that the TAC for the Fladen Ground stock was too low. The estimates of stock abundance provided by the TV survey were used to estimate a likely landings level based on a 'harvest ratio' (catch in numbers/stock abundance in numbers). For the Fladen, an arbitrary conservative harvest ratio of 7.5% was chosen. However, it was recognized that harvest rates in many of the long established *Nephrops* fisheries were likely to be well above this value. At its 2005 meeting ACFM presented expected landings resulting from a range of assumed harvest rates applied to the TV survey abundance estimates from each stock. Although methods for choosing appropriate harvest rates, based on target reference points had been discussed by the assessment WGs, ACFM based their final advice on an option which resulted in landings close to previously reported levels. Since the unreliability of the officially reported landings data had already been highlighted by ACFM, the approach to choosing a harvest rate seemed inconsistent.

As a consequence, the autumn 2005 meeting of STECF was asked to 'identify which harvest rates for stocks of *Nephrops* are consistent with exploiting the stocks at maximum sustainable yields (or suitable proxy)….'. The approach of STECF was to examine a yield-per-recruit (YPR) curve approach. The single sex YPR curves were calculated from a LCA then summed to obtain a combined sex curve. The combined sex fishing mortality (F on the x-axis of the YPR curve) was calculated as the mean F_{bar} (males and females) weighted by number of individuals of each sex caught at the current level of exploitation according to the LCA. It was advised by STECF that a relatively cautious reference point such as $F_{0.1}$ should be used to provide an indication of an appropriate harvest rate. $F_{0.1}$ has been used successfully as a management reference point for Icelandic *Nephrops* stocks and as a reference fishing mortality in New Zealand for both cockles (Morrison and Cryer, 1999) and scallops (Cryer, 1998). Estimates of $F_{0.1}$ as an instantaneous mortality rate were converted to equivalent removal percentages and used as a first approximation of a harvest rate. These turned out to be about 20% for each stock considered. The harvest rates were then applied to the TV survey estimates of total abundance to obtain estimates of sustainable catches. Strictly speaking this approach would apply when the catch is taken in a short time at the time of the survey.

In 2006, the ICES WGs with responsibility for the assessment of *Nephrops* stocks around Scotland provided catch options using harvest ratios equivalent to fishing at $F_{0.1}$ and also with a range of other harvest rates. Although ACFM agreed with the working groups conclusions about stock status they were unhappy with the conclusions about appropriate harvest rate. Their particular concerns related to the derivation of the $F_{0.1}$ from a length-based yield-per-recruit analysis and that the sensitivity of the derived value to the various model assumptions had not been fully tested. Instead they opted to apply a harvest ratio calculated from the ratio of landings to biomass using historical landings and the upper 95% confidence interval of the UWTV survey biomass averaged over the same period. Given the known problems with the historical landings data for many of these stocks, it is likely that a harvest ratio derived in this way is likely to be a substantial underestimate of the actual harvest rate that was being sustained. Additionally for lightly exploited stocks the resulting harvest ratio is likely to be very low and says nothing about potential sustainable harvest ratios. At the 2006 STECF meeting it was therefore recommended that the method previously suggested by STECF in 2005 ($F_{0.1}$ based harvest rate) should be employed to estimated appropriate landings for 2007.

Method

Following comments made by STECF in 2005 and at WKNEPH (ICES, 2006) a working document was presented to WGNSSK (Dobby and Bailey, 2006) which attempted to address a number of the concerns which had been raised with respect to sensitivity of resulting harvest ratios. The calculations carried out used an age-based simulation model in which males and females are modelled separately and is therefore able to account for differences in the way the male and female populations are exploited due to different burrow emergence behaviour. The results showed that a combined sex harvest rate can imply quite different sex-specific fishing mortalities and harvest rates depending on relative burrow emergence of males and females and seasonality of the fisheries. Total harvest ratios equivalent to fishing at $F_{0.1}$ ranged from under 10% to about 25% for the various scenarios tested and in all cases a combined harvest rate of 20% was achieved by fishing at a level between $F_{0.1}$ and F_{max}.

The paper described above makes use of a model which is based only on age and the only phase of the simulation which depends on growth is the calculation of biomass and yield through a von Bertalanffy growth curve to calculate length-at-age and then a weight-length relationship with calculated individual weight. However, it might be expected that *Nephrops* stocks with lower growth rates would require greater fishing pressure to achieve specific harvest ratios.

This paper modifies the Dobby and Bailey (2006) analysis in such a way that the differences in mean growth observed in different *Nephrops* stocks are accounted for in the derivation of the harvest ratio. To do this, the model makes use of a length-based selection pattern. A preliminary retention function was derived at this year's meeting of WGNEPHSEL (report not yet available). The logistic selection pattern used in this model (Figure 1) has parameters chosen so that the shape of the curve is consistent with the length dependent function derived by WGNEPHSEL (Ferro *pers. comm.*) assuming an 80 mm diamond mesh with no lifting bag.

Fishing mortality is assumed to vary between quarters and sexes (in particular mature females) to allow for differences in seasonal burrow emergence and also seasonal differences in fishing effort. Fishing mortality-at-age can therefore be written as

$$F_{s,a,q} = E_q Q_{s,q,a(l)} S_{a(l)}$$

where E_q is a quarterly fishing effort distribution multiplier, $Q_{s,q,a(l)}$ is a catchability multiplier included to account for differences in seasonal availability of males and females (mature and immature) and $S_{a(l)}$ is the age-based selection derived from the length-based selectivity curve.

The other basic features of the population model can be summarized as follows:

- Recruitment at age 1, equal number of males and females
- age (1–15+) and sex-structured population model with a quarterly time increment
- maturity at length assumed knife-edged
- natural mortality independent of quarter, but dependent on sex and maturity: M = 0.2 yr-1 for mature females and 0.3 yr-1 for all others. [Just as fishing mortality is expected to vary with quarter due to variable seasonal emergence, natural mortality probably should too, but this has not been done here!]
- mean growth described by appropriate von Bertalanffy growth parameters (Table 1, adapted from Bailey and Chapman, 1983)
- weight-at-age calculated from mean length-at-age (length at midpoint of age interval) using appropriate length-weight relationship (Table 1, Howard and Hall, 1983)

For a particular set of assumptions (quarterly effort distribution, relative mature female catchability, etc.), equilibrium yields are calculated for the male and female populations separately, then summed to calculate a total yield. Yield-per-recruit curves (Figure 3) are then constructed by repeating the calculation over a range of fishing mortality multipliers. Harvest ratios are calculated as the total number of individuals caught divided by the total number of individuals in the population, either for sexes combined or separately. Additionally they can be calculated with respect to the population summed over a variety of age ranges and in different quarters.

Simulations

Yield-per-recruit calculations are usually carried out using fishing mortalities which have been estimated from an analytic age-based assessment. The approach used here, as there is no analytic assessment, is to look at the sensitivity of the yield-per-recruit derived $F_{0.1}$ and harvest ratios to alternative assumptions about seasonal effort distribution and catchability. For all simulations carried out in this paper, the length-dependent selectivity curve is fixed at that shown in Figure 1 ($L_{50\%}$ = 26 mm, k = 0.2). Dobby and Bailey (2006) presented runs using a number of age-based exploitation patterns (with different levels of declining selectivity at older ages). Harvest rates appeared relatively robust to the changes explored and therefore sensitivity to such changes is not explored further in this paper.

For each stock considered, a number of different assumptions about the catchability of mature females relative to the rest of stock were investigated (i.e. Q=1 except for mature females). Initially the pattern was assumed fixed over quarters and the same for males and females (runs 1–6). Additional model runs were conducted in which catchability of mature females (length >=26 mm) was reduced in quarters 1and 4 (Runs 7–12) and also in all quarters (13–18) to mimic a reduction in fishing mortality due to reduced burrow emergence. This reduction is to a quarter of male fishing mortality in the affected quarters, and although it is not known to what extent lower burrow emergence actually reduces fishing mortality in females, the reduction is probably somewhat less than that assumed here. In other words the option investigated here has been chosen as a rather extreme example (and looks a bit weird!). The exploitation pattern for males and females with reduced catchability is shown in Figure 1.

Different scenarios are also considered for the seasonal effort distribution:

1) effort evenly distributed: 0.25, 0.25, 0.25, 0.25 (Runs 1, 7 and 13)

2) effort distributed according to average effort distribution in the particular stock over most recent couple of years (Runs 6, 12 and 18). See Table 2 for values.

3) effort is concentrated into a single quarter for each of the 4 quarters (all other runs) e.g. 1, 0, 0, 0

For each scenario, harvest ratios can be calculated which are equivalent to fishing at $F_{0.1}$ and F_{max}.. Additionally, the problem can be considered in reverse i.e.. calculating F_{mult}, the sex specific fishing mortality and harvest rates implied by a particular combined sex harvest rate.

The runs are carried out and compared for Clyde *Nephrops* which has a relatively high growth rate and Fladen *Nephrops* which is considered to be one of the slower growing stocks. von Bertalanffy growth curves are shown in Figure 2 and a comparison of the biological input parameters given in Table 1.

Results

The results for each of the stocks are shown in Tables 3–5 and Figure 3 compares sex-specific and combined yield-per-recruit curves for Clyde and Fladen *Nephrops*.

Table 3 compares the combined sex harvest ratios equivalent to fishing at $F_{0.1}$ for Clyde and Fladen *Nephrops* stocks for all scenarios considered. For each stock, harvest ratios are calculated with respect to the population over 2 different age ranges (2–15 and 3–15) and at the beginning of the first and third quarters. The values calculated range from about 9% to 24%. However, much of this variability depends on the definition of the harvest ratio i.e. the choice of age range and quarter for the calculation of population numbers. For example, there is a 10% difference in harvest ratio in Run 1 for Clyde depending on whether the total catch is compared to the population ages 2+ in quarter 1 or 3+ in quarter 3. Similar differences occur in the harvest rates calculated for Fladen *Nephrops*.

As anticipated, the harvest rates equivalent to fishing at $F_{0.1}$ for Fladen *Nephrops* are lower than those calculated for the faster growing Clyde stock. However, the differences are relatively small – generally only a few per cent.

In Scottish waters TV surveys of the main *Nephrops* stocks are carried out between June and August each year and therefore Q3 harvest rates are probably the most sensible to consider. It is also believed that small *Nephrops* (< age 2–3) may live in the burrows of larger individuals and therefore a harvest rate which is calculated with respect to the population numbers summed over individuals aged either 2+ or 3+ is likely to be most appropriate for application to abundance estimates from TV survey burrow counts.

In summary:

- The lowest harvest rates occur when fishing effort is concentrated into quarters with reduced female availability (runs 8, 11) or when female mortality is reduced across all quarters (13–18).
- For a particular definition of harvest rate (e.g. 3+ , Q3) and mature female exploitation pattern (e.g. reduced female emergence in Q1 and Q4) calculated values (16–24%) are relatively robust to assumptions about effort distribution despite some of the scenarios being rather extreme.

Tables 4 and 5 show the sex specific fishing mortality and harvest rates implied by a combined sex harvest rate of 20% for Clyde and Fladen *Nephrops* stocks respectively. Results are shown for harvest rates calculated with respect to Q3 abundance for both age 2+ and 3+ individuals. F_{bar}s are calculated over age ranges used in previous XSA assessments: 3–7 or males and 3–11 for females.

Harvest ratios of 20% with respect to population size calculated over individuals aged 3+ are obviously achieved with lower F_{mult} values than over 2+.

Although many of the combined sex harvest rates of 20% were achieved by fishing at levels greater than $F_{0.1}$, in all simulations, for both Clyde and Fladen, they were equivalent to a fishing mortality less than F_{max} ($F_{0.1}$ and F_{max} values shown in final columns of table). In many of the scenarios for Clyde *Nephrops*, 20% harvest ratios were actually achieved by fishing at levels less than $F_{0.1}$.

In all model runs (for both Clyde and Fladen *Nephrops*), a 20% combined sex harvest ratio implies higher harvest rate of males than females. The length-dependent selectivity pattern when combined with the slower growth of mature females means that fishing mortality is lower, resulting in lower harvest ratios even when the catchability of females and males is the same (runs 1–6). The simulations which have reduced female catchability for either part or all of the year have a much increased male harvest ratio and fishing mortality compared to females. In some extreme cases the harvest ratio of males is 40% while that of females is only 10%.

Achieving harvest ratios of 20% requires higher fishing mortalities for Fladen male and female *Nephrops* compared to Clyde. However, the differences (HR and Fbar) between males and females at Fladen appear less than those observed in the Clyde simulations. The differences in growth rate of Fladen male and female *Nephrops* are smaller than those in Clyde *Nephrops* (Figure 2) and therefore fishing mortality-at-age for males and females at Fladen is more similar than that in the Clyde.

All simulations carried out here with reduced female catchability assume that the reduction is to 25% that of the males. This low percentage almost certainly represents an extreme case. Higher female Fs throughout the simulation would tend to push up the harvest rates for a given scenario in Tables 4–5 and reduce the relative mortality on males.

Additionally, the same length dependent selectivity function is assumed for both Fladen and Clyde *Nephrops*. Clearly the shape of this curve will depend on the mix of vessels and gears targeting the stock and is therefore unlikely to be the same for the two different stocks.

Summary

- For simulations conducted here, harvest rates equivalent to fishing at $F_{0.1}$ vary from under 9% up to about 25% with the lowest values occurring in runs with reduced female catchability
- Achieving a combined sex harvest rate of 20% across the range of scenarios explored here implies fishing at a level between $F_{0.1}$ and $F_{max.}$
- Combined sex harvest rates can imply quite different sex-specific fishing mortalities and harvest rates depending on the relative burrow emergence of males and females and the seasonality of the fisheries
- All these simulations are assuming steady state conditions and further simulations need to be explored with varying recruitment.

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Table 1. Biological input parameters for population model.

FU	DISCARD SURVIVAL	MALES					FEMALES					
		k	Linf	M	a	b	K	Linf	L Mat	M	a	b
North Minch	0.25	0.16	70	0.3	0.00028	3.24	0.16	70	27	0.3	0.00085	2.91
							0.06	60		0.2	0.00085	2.91
South Minch	0.25	0.161	68	0.3	0.00028	3.24	0.161	68	25	0.3	0.00089	2.91
							0.06	59		0.2	0.00089	2.91
Clyde	0.25	0.16	73	0.3	0.00028	3.24	0.16	73	27	0.3	0.00085	2.91
							0.06	62		0.2	0.00085	2.91
Moray Firth	0.25	0.165	62	0.3	0.00028	3.24	0.165	62	25	0.3	0.00074	2.91
							0.06	56		0.2	0.00074	2.91
Fladen	0.25	0.16	66	0.3	0.0003	3.25	0.16	66	25	0.3	0.00074	2.91
							0.1	56		0.2	0.00074	2.91
Firth of Forth	0.25	0.163	66	0.3	0.00028	3.24	0.163	66	26	0.3	0.00085	2.91
							0.065	58		0.2	0.00085	2.91

Table 2. Average quarterly effort distribution (2005–2006).

	Q1	Q2	Q3	Q4
Clyde	0.2185	0.2563	0.2770	0.2481
Firth of Forth	0.1977	0.2316	0.3437	0.2270
Fladen	0.2257	0.2921	0.3033	0.1789
Moray Firth	0.1555	0.2207	0.4204	0.1080
North Minch	0.2295	0.2735	0.2991	0.1979
South Minch	0.2313	0.3148	0.2696	0.1842

Table 3. Comparison of harvest rates equivalent to $F_{0.1}$ with a range of quarterly effort distributions and relative mature female availability.

	QUARTERLY EFFORT DISTRIBUTION	M/F EXPLOITATION PATTERN	CLYDE HARVEST RATIOS						FLADEN HARVEST RATIOS			
			FMULT	AGES 2+	AGES 3+	FMULT	AGES 2+	AGES 3+				
				Q1	Q3	Q1	Q3		Q1	Q3	Q1	Q3
Run1	Even	Same	0.21	0.124	0.1509	0.1852	0.2269	0.21	0.1114	0.1346	0.1642	0.2
Run2	Q1	Same	0.2	0.1149	0.1477	0.1683	0.2215	0.21	0.1081	0.138	0.1572	0.2059
Run3	Q2	Same	0.21	0.1224	0.1597	0.182	0.2424	0.21	0.1101	0.1419	0.1616	0.213
Run4	Q3	Same	0.21	0.1253	0.1429	0.1882	0.2125	0.21	0.1124	0.1281	0.1664	0.188
Run5	Q4	Same	0.21	0.1284	0.1464	0.1945	0.2197	0.21	0.1147	0.1308	0.1715	0.1937
Run6	Effort dist	Same	0.21	0.1241	0.1506	0.1856	0.2264	0.21	0.1112	0.1348	0.1639	0.2002
Run7	Even	Reduced mat F Q1 and Q4	0.23	0.1151	0.139	0.1692	0.2046	0.24	0.1064	0.128	0.1552	0.1873
Run8	Q1	As 7	0.25	0.0894	0.111	0.1258	0.1561	0.27	0.0846	0.1045	0.1185	0.147
Run9	Q2	As 7	0.21	0.1224	0.1597	0.182	0.2424	0.21	0.1101	0.1419	0.1616	0.213
Run10	Q3	As 7	0.21	0.1253	0.1429	0.1882	0.2125	0.21	0.1124	0.1281	0.1664	0.188
Run11	Q4	As 7	0.25	0.1028	0.1167	0.1485	0.167	0.27	0.0956	0.1086	0.1374	0.1545
Run12	Effort dist	As 7	0.23	0.1168	0.1408	0.1721	0.2078	0.23	0.1061	0.1279	0.1548	0.1873
Run13	Even	Reduced mat F all Q	0.25	0.0959	0.1142	0.1368	0.1618	0.27	0.0899	0.1068	0.1276	0.1509
Run14	Q1	As 13	0.25	0.0894	0.111	0.1258	0.1561	0.27	0.0846	0.1045	0.1185	0.147
Run15	Q2	As 13	0.25	0.0935	0.1172	0.1328	0.1653	0.27	0.0879	0.1096	0.1242	0.1547
Run16	Q3	As 13	0.25	0.0981	0.1114	0.1405	0.158	0.27	0.0916	0.1041	0.1306	0.1468
Run17	Q4	As 13	0.25	0.1028	0.1167	0.1485	0.167	0.27	0.0956	0.1086	0.1374	0.1545
Run18	Effort dist	As 13	0.25	0.0962	0.1142	0.1372	0.1619	0.27	0.0897	0.1067	0.1272	0.1507

Table 4. Clyde *Nephrops*. Sex specific fishing mortality and harvest rates when applying a total harvest rate of 20%. Results shown for harvest rates calculated relative to abundance in Q3 for both 3+ and 2+ individuals.

	HR in Q3 ages 3+					HR in Q3 ages 2+						
		Male		Female			Male		Female		Fmult	
	Fmult	Fbar (3–7)	HR	Fbar (3–11)	HR	Fmult	Fbar (3–7)	HR	Fbar (3–11)	HR	F0.1	Fmax
Run1	0.18	0.165	0.2136	0.1499	0.1766	0.28	0.2566	0.2071	0.2331	0.1889	0.21	0.39
Run2	0.18	0.1591	0.2199	0.1468	0.1809	0.27	0.2387	0.2068	0.2202	0.1879	0.2	0.39
Run3	0.17	0.1545	0.2136	0.1407	0.1747	0.26	0.2363	0.2081	0.2151	0.1881	0.21	0.39
Run4	0.19	0.1764	0.2122	0.1593	0.1769	0.3	0.2786	0.2041	0.2515	0.1875	0.21	0.39
Run5	0.19	0.1794	0.2181	0.1613	0.1825	0.29	0.2739	0.2043	0.2462	0.1887	0.21	0.4
Run6	0.18	0.1652	0.2131	0.15	0.1762	0.28	0.257	0.2065	0.2333	0.1885	0.21	0.39
Run7	0.22	0.2016	0.2657	0.1145	0.1512	0.33	0.3024	0.241	0.1718	0.1638	0.23	0.43
Run8	0.31	0.2741	0.4076	0.0632	0.105	0.46	0.4067	0.3426	0.0938	0.122	0.25	0.51
Run9	0.17	0.1545	0.2136	0.1407	0.1747	0.26	0.2363	0.2081	0.2151	0.1881	0.21	0.39
Run10	0.19	0.1764	0.2122	0.1593	0.1769	0.3	0.2786	0.2041	0.2515	0.1875	0.21	0.39
Run11	0.29	0.2739	0.3432	0.0615	0.1214	0.43	0.4061	0.2889	0.0912	0.1382	0.25	0.54
Run12	0.22	0.2019	0.265	0.1191	0.1559	0.33	0.3028	0.2403	0.1787	0.1679	0.23	0.43
Run13	0.3	0.2749	0.3756	0.0624	0.1134	0.44	0.4032	0.3138	0.0916	0.1291	0.25	0.51
Run14	0.31	0.2741	0.4076	0.0632	0.105	0.46	0.4067	0.3426	0.0938	0.122	0.25	0.51
Run15	0.29	0.2635	0.3997	0.06	0.1069	0.42	0.3817	0.3359	0.0869	0.1228	0.25	0.51
Run16	0.31	0.2879	0.3517	0.065	0.1195	0.47	0.4365	0.2973	0.0985	0.138	0.25	0.52
Run17	0.29	0.2739	0.3432	0.0615	0.1214	0.43	0.4061	0.2889	0.0912	0.1382	0.25	0.54
Run18	0.3	0.2753	0.3744	0.0625	0.1138	0.44	0.4038	0.3127	0.0917	0.1295	0.25	0.51

Table 5. Fladen *Nephrops*. Sex specific fishing mortality and harvest rates when applying a total harvest rate of 20%. Results shown for harvest rates calculated relative to abundance in Q3 for both 3+ and 2+ individuals.

	HR in Q3 ages 3+					HR in Q3 ages 2+						
		Male		Female			Male		Female		Fmult	
	Fmult	Fbar (3–7)	HR	Fbar (3–11)	HR	Fmult	Fbar (3–7)	HR	Fbar (3–11)	HR	F0.1	Fmax
Run1	0.21	0.1807	0.2165	0.174	0.1876	0.32	0.2754	0.2016	0.2652	0.1912	0.21	0.4
Run2	0.2	0.1638	0.2117	0.1613	0.1835	0.31	0.2538	0.2023	0.2501	0.1918	0.21	0.39
Run3	0.19	0.1614	0.2076	0.1562	0.1789	0.3	0.2548	0.2047	0.2466	0.1933	0.21	0.39
Run4	0.22	0.1927	0.2123	0.184	0.185	0.35	0.3065	0.2018	0.2928	0.1918	0.21	0.4
Run5	0.21	0.1886	0.2087	0.1785	0.1824	0.34	0.3054	0.2032	0.2889	0.194	0.21	0.4
Run6	0.2	0.1718	0.206	0.1656	0.1786	0.32	0.2749	0.2019	0.2649	0.1914	0.21	0.4
Run7	0.25	0.2151	0.26	0.1295	0.1547	0.39	0.3356	0.2399	0.2021	0.1699	0.24	0.44
Run8	0.36	0.2948	0.4021	0.0726	0.108	0.54	0.4422	0.3333	0.1089	0.1243	0.27	0.56
Run9	0.19	0.1614	0.2076	0.1562	0.1789	0.3	0.2548	0.2047	0.2466	0.1933	0.21	0.39
Run10	0.22	0.1927	0.2123	0.184	0.185	0.35	0.3065	0.2018	0.2928	0.1918	0.21	0.4
Run11	0.34	0.3054	0.3426	0.0722	0.1221	0.52	0.467	0.2895	0.1105	0.1414	0.27	0.56
Run12	0.24	0.2062	0.2493	0.1386	0.1608	0.37	0.3179	0.2295	0.2136	0.1727	0.23	0.43
Run13	0.35	0.3012	0.3729	0.0725	0.115	0.53	0.4561	0.3132	0.1098	0.1331	0.27	0.55
Run14	0.36	0.2948	0.4021	0.0726	0.108	0.54	0.4422	0.3333	0.1089	0.1243	0.27	0.56
Run15	0.34	0.2888	0.4015	0.0699	0.1099	0.5	0.4247	0.3324	0.1028	0.1259	0.27	0.56
Run16	0.36	0.3153	0.3456	0.0753	0.1194	0.56	0.4904	0.293	0.1171	0.1392	0.27	0.56
Run17	0.34	0.3054	0.3426	0.0722	0.1221	0.52	0.467	0.2895	0.1105	0.1414	0.27	0.56
Run18	0.35	0.3007	0.3736	0.0724	0.1144	0.53	0.4554	0.314	0.1097	0.1325	0.27	0.55

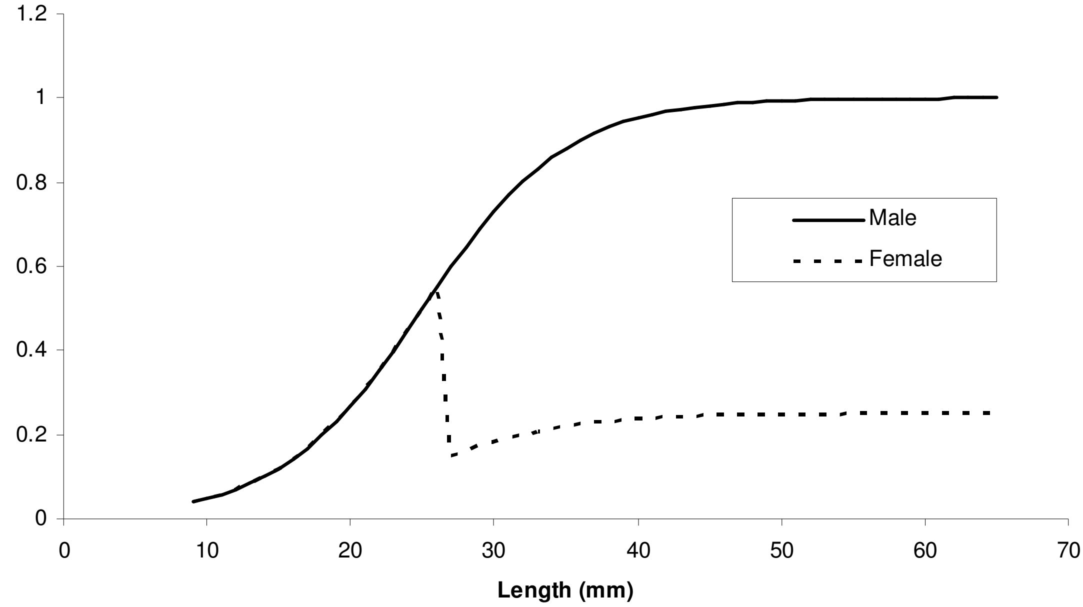

Figure 1. Input length-dependent selection pattern. Female exploitation reduced at mature sizes to mimic reduced emergence from burrows of mature females.

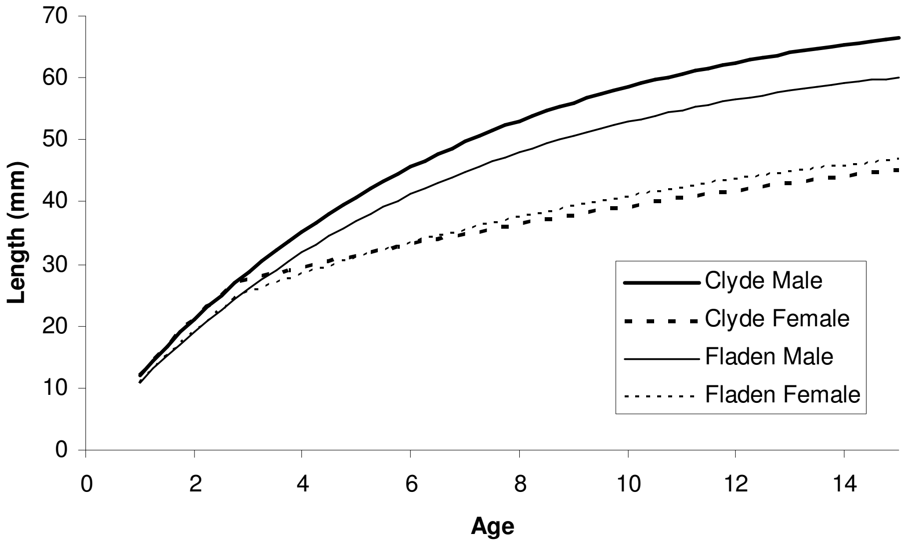

Figure 2. Comparison of von Bertalanffy growth curves for male and female *Nephrops* in the Clyde and Fladen.

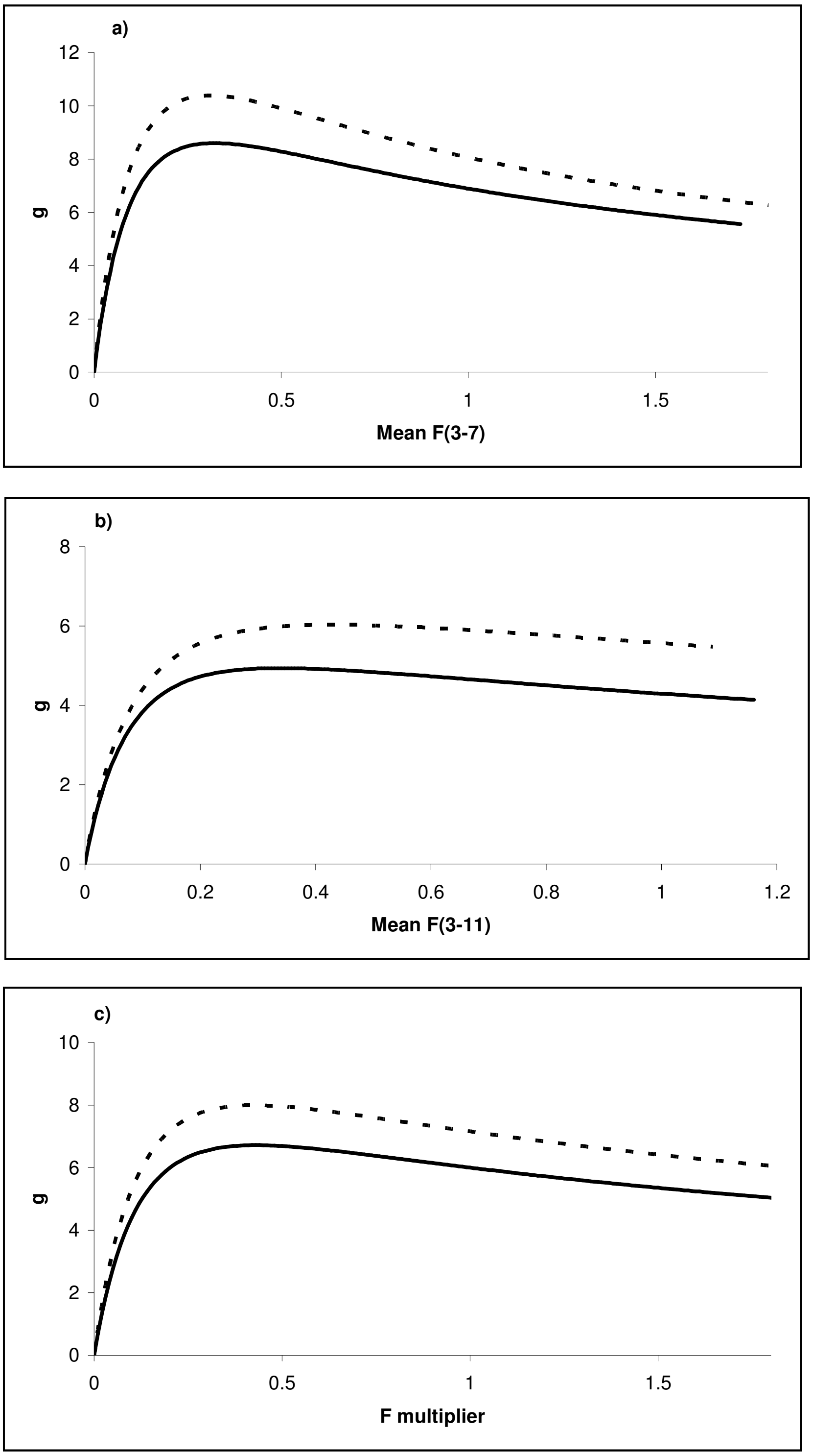

Figure 3. YPR curves for a) males, b) females and c) sexes combined for flat-topped exploitation pattern with reduced exploitation of mature females in Q1 and Q4. (- - - - Clyde,------- Fladen).

Working Document 7

Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1) and Wiararapa / Hawke Bay (SCI 2).

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EXECUTIVE SUMMARY

Tuck, I.; Dunn, A. (2006). Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1) and Wairarapa / Hawke Bay (SCI 2).
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This report updates and develops the Bayesian, length-based, two-sex population model for Bay of Plenty (SCI 1) scampi, previously described by Cryer at al. (2005), and also develops a population model for Wairarapa / Hawke Bay (SCI 2) scampi. Cryer at al. (2005) documented the first attempt at developing a length-based population model for any scampi stock, implemented using the general-purpose stock assessment program CASAL. Developments in the model implementation and structure have been largely based on suggestions raised at Shellfish Fisheries Assessment Working Group (SFAWG) meetings in 2005 and 2006.

The models offered as base models represent some of the data reasonably well, but do not represent well commercial or research trawl catch effort data, or the observed changes in sex ratio. Sensitivity and likelihood profile investigations indicate that the length distribution data from commercial and research trawling are inconsistent between time steps in the current model configuration, suggesting that allowing availability to the gear (represented by selectivity within the model) to vary between time steps may be appropriate, although further examination of the time steps used in the model may also be required. An alternative approach to modelling the growth data (still external to the model, but combining immature females with all the male data) was also investigated.

The preliminary nature of the model development should be borne in mind when considering the model outputs in relation to the state of stocks. Outputs were sensitive to a number of relatively poorly known parameters (including prior constraints on year class strength variability and q-Photo). However, B_{2005} as a proportion of B_0 tended to be quite consistent amongst runs, and was generally 74 – 89 % for SCI 1, and 40 – 55 % for SCI 2.

A number of potential model developments were identified, including further investigation into seasonal and sex related variability in availability to the fishery, spatial stratification of the model, incorporation of a minimum estimated biomass from the photo survey, incorporation of a biomass estimate from tag recapture data, estimating growth within the model and developing a multi-stock model for SCI 1 and SCI 2.

1 INTRODUCTION

This report updates and develops the Bayesian, length-based, two-sex population model for Bay of Plenty (SCI 1) scampi, previously described by Cryer at al. (2005), and also develops a population model for Wairarapa / Hawke Bay (SCI 2) scampi. Cryer at al. (2005) documented the first attempt at developing a length-based population model for any scampi stock, implemented using the general-purpose stock assessment program CASAL v2.06 (September 2004, Bull et al. 2004). The current study used CASAL v 2.09 (September 2006). Developments in the model implementation and structure have been largely based on suggestions raised at Shellfish Fisheries Assessment Working Group (SFAWG) meetings in 2005 and 2006.

We describe the available data and how they were used, the parameterisation of the model, and model fits and sensitivity. The model has many inadequacies, but we nevertheless provide a preliminary estimate of current stock status. This report fulfils Objective 3 of Project SCI2004/01 "*To further develop stock assessment of scampi in QMA 1, including estimating biomass and sustainable yields*" and Objectives 2 and 3 of Project SCI2005/01 "*To update and revise the stock assessment model for SCI 1, including estimating biomass and yield*" and also "*To start the development of a stock assessment model for SCI 2*".

1.1 Description of the fishery

The New Zealand trawl fishery for scampi developed first in SCI 1 in 1987–88. It has been conducted mainly by 20–40 m vessels using light, bottom trawl rigs consisting of two or three nets of very low headline height. Currently, the main fisheries are in waters 300–550 m deep in SCI 1 (Bay of Plenty), SCI 2 (Hawke Bay and Wairarapa Coast), SCI 3 (Mernoo Bank) SCI 4 (western Chatham Rise and Chatham Islands) and SCI 6A (Sub-Antarctic) (Figure 1, Table 1). Some fishing has been reported on the Challenger Plateau outside the EEZ.

Scampi was introduced into the QMS on 1 October 2004. Until the introduction, access to the fishery had been restricted and, until the 1999–00 fishing year, there were restrictions on the vessels that could be used in each SCI. Until the 2001–02 fishing year, catches were restrained using a mixture of competitive and individually allocated catch limits. For the 2001–02 to 2003–04 fishing years, all scampi fisheries were managed using competitive catch limits, that for SCI 1 being 120 t and for SCI 2 being 246 t. In the 2004-05 fishing year under the QMS, catch limits were 120 t for SCI 1 and 200 t for SCI 2.

In SCI 1, CPUE increased through the early 1990's, peaking in 1995-96, and then declining until 2002 (Figure 2). CPUE increased between 2002 and 2003, but has declined again since this time. CPUE in 2004-05 was 40% of that in 1988-89. Where examined, the unstandardised CPUE series have been found to be highly correlated with standardised series, suggesting that the unstandardised CPUE is a reliable index of overall catch rate. Concerns have been raised, however, that CPUE may not reflect stock abundance, owing to possible changes in catchability. The depths range fished has remained around 400 m since 1988–89 (although some shallower tows were made 1991–92 to 1994–95, and again since 2000–01; Figure 3), and the spatial extent of the fishery has remained reasonably consistent in the western Bay of Plenty (Figure 5).

In SCI 2, CPUE increased slowly in the early 1990's, with a sharp increase in 1995 to a peak, after which CPUE showed a steady decline to 2002 (Figure 2). Since 2002, CPUE has shown a slow increase, and in 2004-05, was 37% of that in 1989-90. The depths range fished has remained slightly shallower than 400 m since 1988–89 (although some shallower tows were made in 1992-93, and some deeper tows have been made in more recent years; Figure 4), and the spatial extent of the fishery has remained reasonably consistent, with activity in Hawke Bay and Wairarapa areas (Figure 6).

In both fisheries, discussions with fishers suggest that trawl mesh sizes have remained similar or identical since about 1993, although some fishers used finer meshes in the early years of the fishery. TCEPR or observer records do not provide sufficient information to examine this. Thus, fishing practice seems to have been reasonably consistent, at least since 1993.

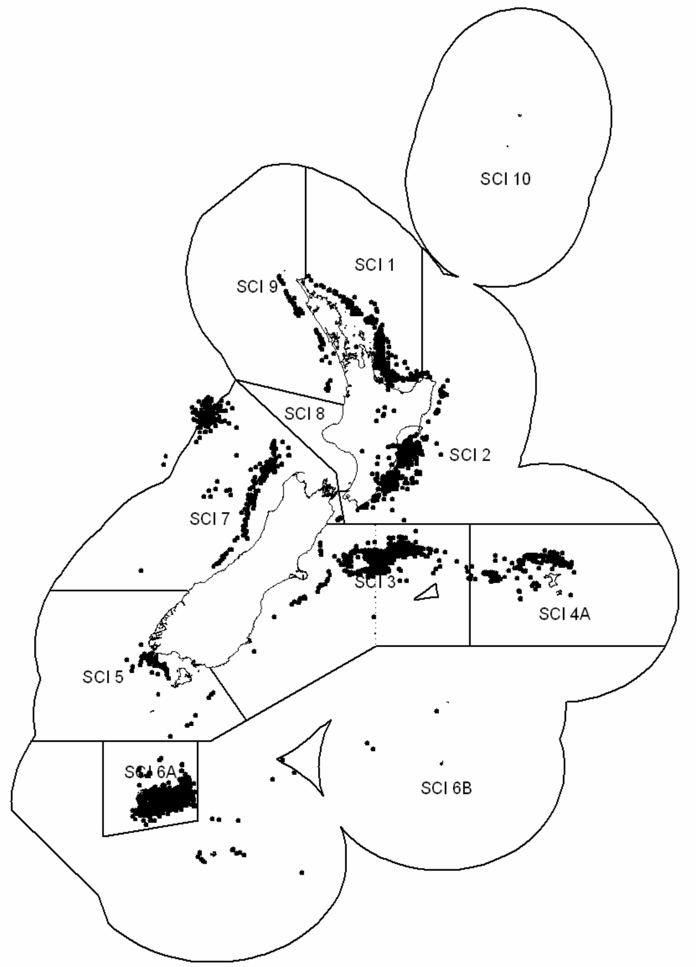

Figure 1: Fishery management areas and the locations of the main fishing areas for scampi, *Metanephrops challengeri*, in New Zealand waters. Dots indicate start positions of all trawl tows targeting scampi on Ministry of Fisheries catch/effort databases to the end of the 2004-05 fishing year. The dashed line within SCI 3 represents the previous boundary between SCI 3 and SCI 4W.

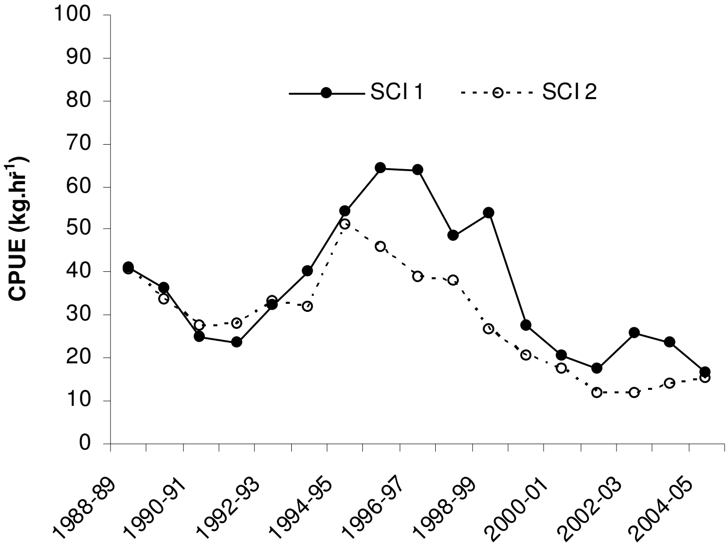

Figure 2: Unstandardised catch rates for scampi in SCI 1 and SCI 2 (total catch (kg) divided by total effort (hours)) with tows of zero scampi catch excluded.

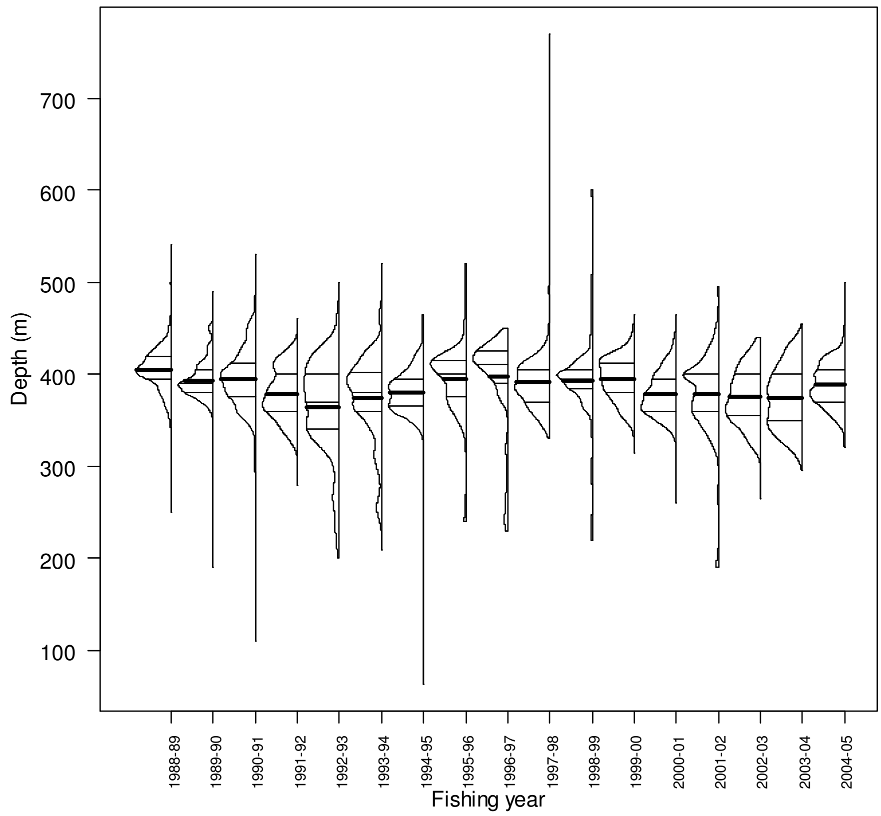

Figure 3: Depth distribution of trawl tows for scampi by fishing year in SCI 1.

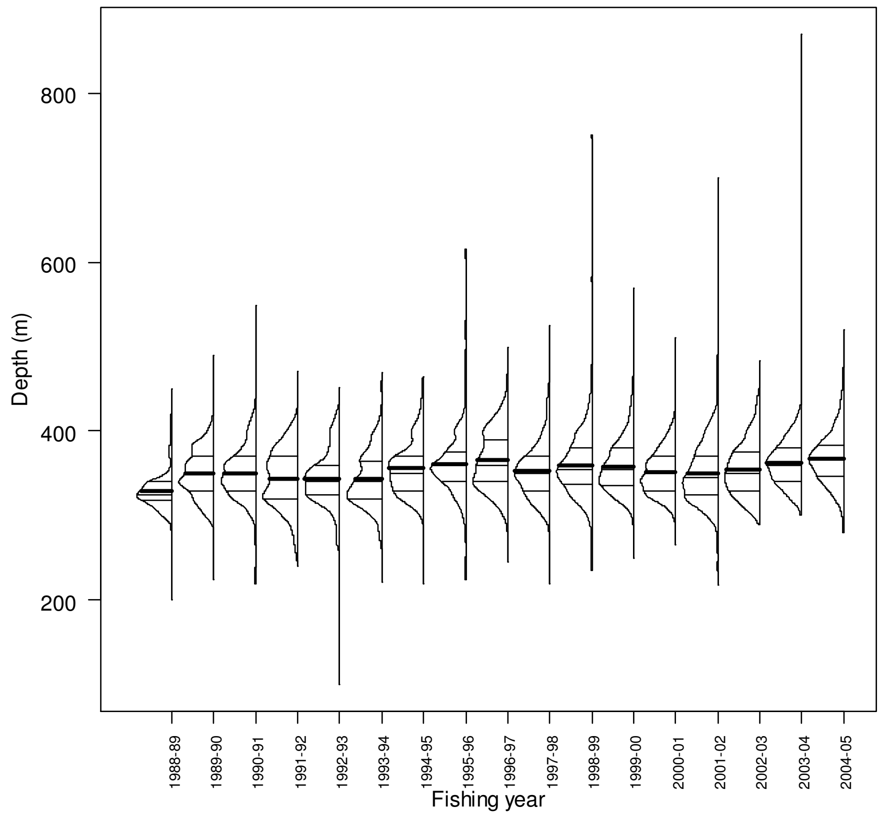

Figure 4: Depth distribution of trawl tows for scampi by fishing year in SCI 2.

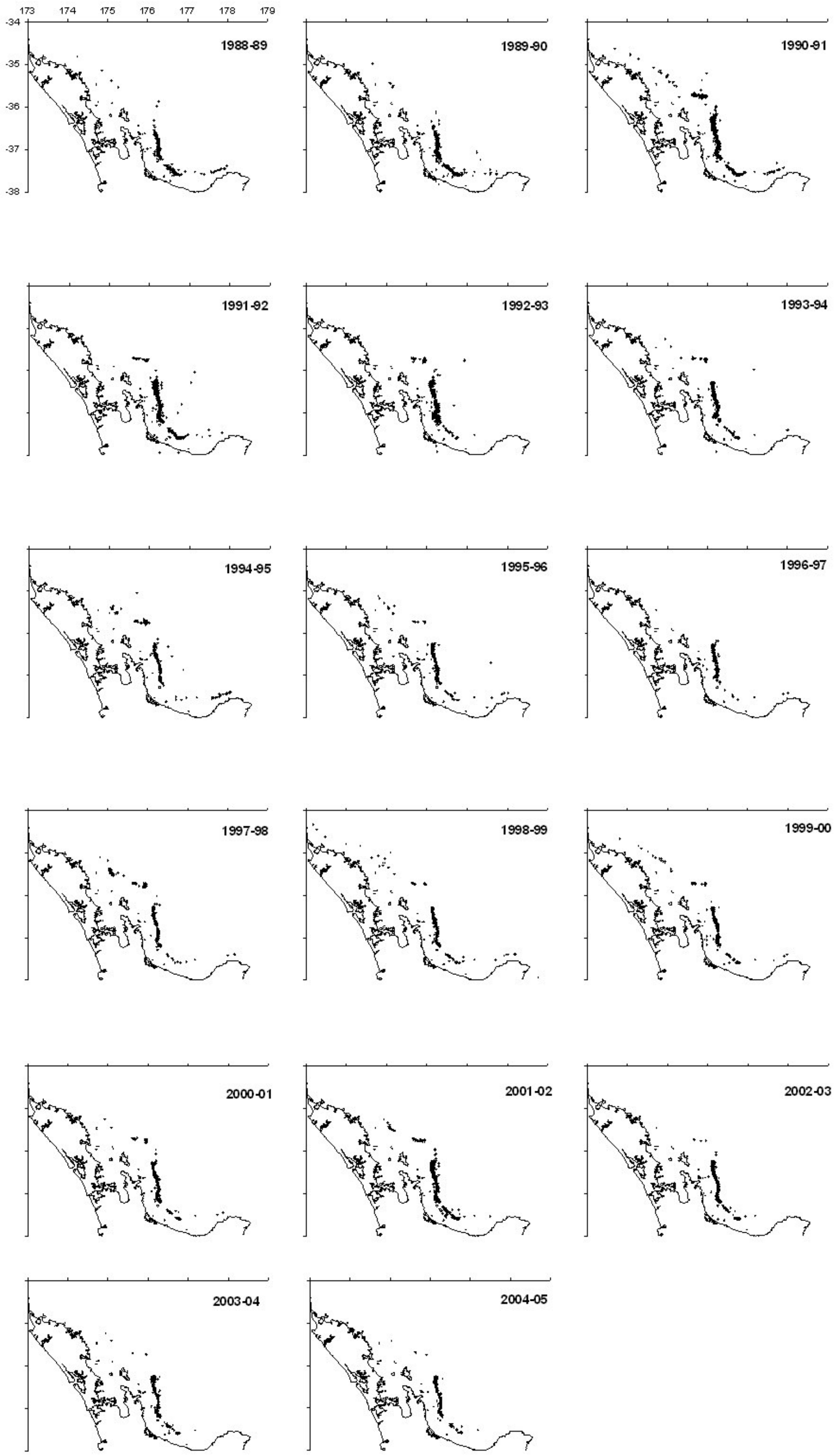

Figure 5: Spatial distribution of the SCI 1 scampi trawl fishery since 1988-89. Each dot shows the start position of a tow reported on TECPR.

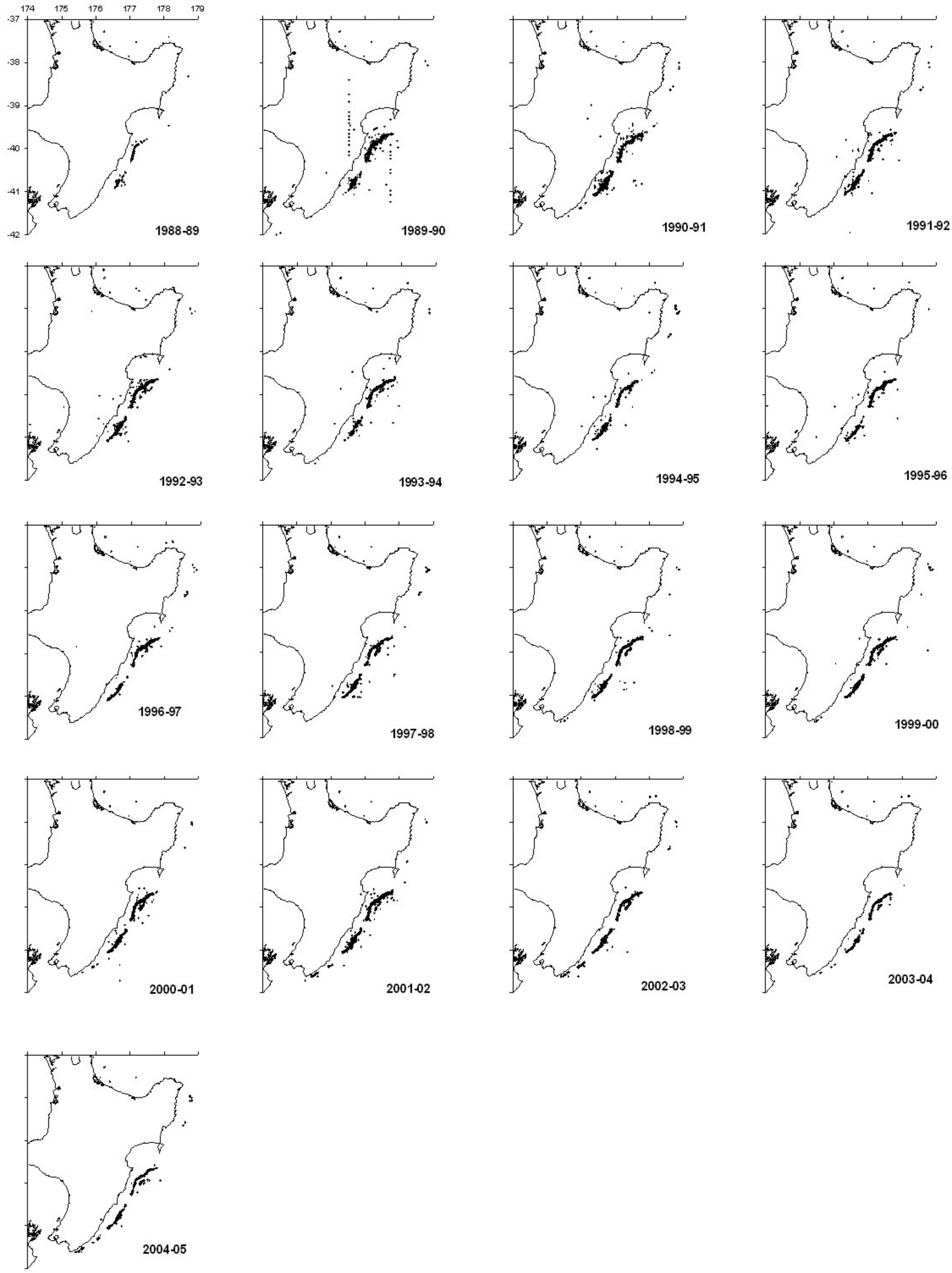

Figure 6: Spatial distribution of the SCI 2 scampi trawl fishery since 1988-89. Each dot shows the start position of a tow reported on TECPR.

Table 1: Estimated commercial landings (t) from the 1986–87 to 2004–05 fishing years (based on management areas in force since introduction to the QMS in October 2004) and catch limits (t) by SCI (from CLR and TCEPR, MFish landings and catch effort databases, early years may be incomplete). No limits before 1991–92 fishing year, (†) catch limits allocated individually until the end of 2000–01. *Note that management areas SCI 3, 4, 6A and 6B changed in October 2004, and the catch limits applied to the old areas are not relevant to the landings based on the new management areas.

	SCI 1		SCI 2		SCI 3		SCI 4A		SCI 5	
	Landings	Limit (†)	Landings	Limit (†)	Landings	Limit	Landings	Limit (†)	Landings	Limit
1986–87	5	–	0	–	0	–	0 –	–	–	–
1987–88	15	–	5	–	0	–	0	–	0	–
1988–89	60	–	17	–	0	–	0	–	0	–
1989–90	104	–	138	–	0	–	0	–	0	–
1990–91	179	–	295	–	0	–	32	–	0	–
1991–92	132	120	221	246	153	–	78	–	0	60
1992–93	114	120	210	246	296	–	11	–	2	60
1993–94	115	120	244	246	325	–	0	–	1	60
1994–95	114	120	226	246	292	–	0	–	0	60
1995–96	117	120	230	246	306	–	0	–	0	60
1996–97	117	120	213	246	304	–	0	–	2	60
1997–98	107	120	224	246	296	–	0	–	0	60
1998–99	110	120	233	246	293	–	27	–	30	60
1999–00	124	120	193	246	322	–	23	–	9	40
2000–01	120	120	146	246	333	–	0	–	7	40
2001–02	124	120	247	246	306	–	28	–	<1	40
2002–03	121	120	134	246	265	–	78	–	7	40
2003–04	120	120	64	246	276	–	42	–	5	40
2004-05*	109	120	71	200	335	340	101	120	1	40

	SCI 6A		SCI 6B		SCI 7		SCI 8		SCI 9	
	Landings	Limit (†)	Landings	Limit	Landings	Limit	Landings	Limit	Landings	Limit
1986–87	0	–	0	–	0	–	0	–	0	–
1987–88	0	–	0	–	0	–	0	–	0	–
1988–89	0	–	0	–	0	–	0	–	0	–
1989–90	0	–	0	–	0	–	0	–	0	–
1990–91	2	–	0	–	0	–	0	–	0	–
1991–92	325	–	0	–	0	75	0	60	0	60
1992–93	279	–	0	–	2	75	0	60	2	60
1993–94	303	–	0	–	0	75	0	60	1	60
1994–95	239	–	0	–	2	75	0	60	0	60
1995–96	270	–	0	–	1	75	0	60	0	60
1996–97	275	–	0	–	0	75	0	60	0	60
1997–98	279	–	0	–	0	75	0	60	0	60
1998–99	325	–	<1	–	1	75	0	60	<1	60
1999–00	328	–	0	–	1	75	0	5	0	35
2000–01	264	–	0	–	<1	75	0	5	0	35
2001–02	272	–	0	–	<1	75	0	5	0	35
2002–03	255	–	0	–	<1	75	0	5	0	35
2003–04	311	–	0	–	1	75	0	5	0	35
2004-05*	295	306	0	50	1	75	0	5	0	35

1.2 General biological knowledge

Scampi are widely distributed around the New Zealand coast, principally in depths between 200 and 500 m on the continental slope. Like other species of *Metanephrops* and *Nephrops*, *M. challengeri* builds a burrow in the sediment and may spend a considerable proportion of time within this burrow. From trawl catch rates, it appears that there are daily and seasonal cycles of emergence from burrows onto the sediment surface.

Scampi moult several times per year in early life and probably about once a year after sexual maturity (at least in females). Early work suggested that female *M. challengeri* achieve sexual maturity at about 40 mm orbital carapace length (OCL) in the Bay of Plenty and on the Chatham Rise, about 36 mm OCL off the Wairarapa coast, and about 56 mm OCL around the Auckland Islands. Work on more recent trawl surveys in SCIs 1 and 2 suggest that 50% of females were mature at 30 mm OCL in these areas. The peak of moulting and spawning activity seems to occur in spring or early summer. Larval development of *M. challengeri* is probably very short, and may be less than 3 days in the wild.

The abbreviated larval phase may, in part, explain the low fecundity of *M. challengeri* compared with *N. norvegicus* (that of the former being about 10–20% that of the latter).

Relatively little is known of the growth rate of any of the *Metanephrops* species in the wild. Tagging of *M. challengeri* to determine growth rates was undertaken in the Bay of Plenty in 1995, and the bulk of recaptures were made late in 1996. About 1% of tagged animals were recaptured, similar to the average return rate of similar tagging studies for trawl caught scampi overseas. Many more females than males were recaptured, and small males were almost entirely absent from the recapture sample. Scampi captured and tagged at night were much more likely to be recaptured than those exposed to sunlight. Estimates from this work of growth rate and mortality for females are given in Table 2. The data for males were insufficient for analysis, although the average annual increment with size appeared to be greater than in females.

Table 2: Estimates of biological parameters.

Population	Estimate			Source
1. Weight = a(orbital carapace length)^b (weight in g, OCL in mm)				
All males: SCI 1	a = 0.000373	b = 3.145		Cryer & Stotter (1997)
Ovigerous females: SCI 1	a = 0.003821	b = 2.533		Cryer & Stotter (1997)
Other females: SCI 1	a = 0.000443	b = 3.092		Cryer & Stotter (1997)
All females: SCI 1	a = 0.000461	b = 3.083		Cryer & Stotter (1997)
2. von Bertalanffy growth parameters				
	K (yr^{-1})	**L_∞ (OCL, mm)**	**t_0 (yr)**	
Females: SCI 1 (tag)	0.11–0.14	48.0–49.0	0.0	Cryer & Stotter (1999)
Females: SCI 2 (aquarium)	0.31	48.8	0.0	Cryer & Oliver (2001)
Males: SCI 2 (aquarium)	0.32	51.2	0.0	Cryer & Oliver (2001)
3. Natural mortality (M)				
Females: SCI 1	M = 0.20–0.25			Cryer & Stotter (1999)

Scampi from SCI2 were successfully reared in aquariums for over 12 months in 1999–2000. Results from these growth trials suggested a von Bertalanffy K of about 0.3 for both sexes, compared with <0.15 for the tagging trial. Extrapolating the length-based results to age-based curves suggests that scampi are about 3–4 years old at 30 mm carapace length and may live for 15 years. There are many uncertainties with captive reared animals, however, and these estimates should not be regarded as definitive. In particular, the rearing temperature was 12º C compared with about 10º C in the wild (in SCIs 1 and 2), and the effects of captivity are largely unknown.

The maximum age of New Zealand scampi is not known, although analysis of tag return data and aquarium trials suggest that this species may be quite long lived. *Metanephrops* spp in Australian waters may grow rather slowly and take up to 6 years to recruit to the commercial fishery, consistent with estimates of growth in *M. challengeri* (Table 2). *N. norvegicus* populations in some northern European populations are thought to achieve a maximum age of 15–20 years, consistent with the estimates of natural mortality, M, for *M. challengeri*.

2 MODEL STRUCTURE, INPUTS AND ESTIMATION

The starting point for model development is the base model for SCI 1, as described by Cryer at al. (2005). Particular issues for consideration raised by the SFAWG included the inclusion of the commercial CPUE series, priors (particularly for q-photo), recruitment variation, the commercial and research trawl selectivity data and the representativeness of the observer length frequency data. The modelling growth within the assessment model was also raised as a possibility, but is beyond the scope of the current project, and will be considered in any future model development.

2.1 General structure of the model

Model structure is as described by Cryer at al. (2005). The scampi populations within each SCI are considered in separate models.

SCI 1

The population model partitions the scampi in SCI 1 into a two-sex population, with sixty-six length bins having lower limits of 1–66 mm orbital carapace length (OCL), the last being a "plus group". The "stock" is assumed to reside in a single, homogeneous area between the Mercury Islands and White Island, 300–500 m depth (Figure 11).

SCI 2

The population model partitions the scampi in SCI 2 into a two-sex population, with seventy-six length bins having lower limits of 1–76 mm orbital carapace length (OCL), the last being a "plus group". The "stock" is assumed to reside in a single, homogeneous area between the Mahia Peninsula and Castle Point, 300–500 m depth (Figure 12).

In both models, the partition accounts numbers of males and females by length class within an annual cycle, where movements between length classes are determined by sex-specific, length-based growth parameters. Individuals enter the partition by recruitment and are removed by natural mortality and fishing mortality. The model's annual cycle is based on the fishing year and is divided into two time-steps (Table 3). Note that model references to "year" within this report refer to the fishing year, and are labelled as the most recent calendar year, i.e., the fishing year 1998–99 is referred to as "1999" throughout.

Table 3: Annual cycle of the population model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur together within a time step occur after all other processes, with 50% of the natural mortality for that time step occurring before and 50% after the fishing mortality.

Step	Period	Process	Proportion in time step
1	Oct–Dec	Recruitment	1.0
		Maturation	1.0
		Natural mortality	0.25
		Fishing mortality	From TCEPR
2	Jan–Sep	Natural mortality	0.75
		Growth	1.0
		Fishing mortality	From TCEPR

Catches occur in both time steps during the years 1985–86 to 2004–05 (see Table 1 for the whole SCIs, Table 4 and Table 5 for the modelled areas of SCI 1 and SCI 2) and we divided the catch among the two according to the proportion of estimated catches recorded on Trawl Catch, Effort, and Processing Returns (TCEPR). Recreational catch, customary catch, and illegal catch are ignored. The maximum exploitation rate (i.e., the ratio of the maximum catch to biomass in any year) is not known, but we constrained it to no more than 0.9 in a time-step (i.e., we assume that no more than 90% of the stock can be taken in a time step). Individuals are assumed to recruit to the model at age 1, with the mean expectation of recruitment success predicted by a Beverton & Holt stock-recruitment relationship. Length at recruitment is defined by a normal distribution with mean of 10 mm OCL with a c.v. of 0.4. Relative year class strengths are encouraged to average 1.0. Growth is assumed known (from tag and aquarium data), but natural mortality is estimated.

The model uses three asymmetrical (Richards) length-based selectivity ogives for commercial fishing, research trawl surveys, and photographic surveys (all assumed constant over both sexes, all years, and all time steps of the fishery in the initial implementation of the model). A length-based symmetrical (logistic) maturity ogive is used, and assumed to be identical for males and females (though we have data only for the latter). The logistic curve is parameterised for each length class x as:

$$f(x) = 1 \Big/ \left[1 + 19^{(a_{50} - x)/a_{to95}}\right]$$

where x is the centre of the length class and estimable parameters are a_{50} and a_{to95}. Richards curves are more complex and involve an asymmetry term as well as the terms describing central tendency and steepness:

$$f(x) = \left(1 \Big/ \left[1 + 19^{(\alpha - x)/\beta}\right] \right)^{\frac{1}{\delta}}$$

where

$$\beta = \frac{a_{to95} \log(19)}{\log\left(2^{\delta} - 1\right) - \log\left(\left(\frac{20}{19}\right)^{\delta} - 1\right)}$$

and

$$\alpha = a_{50} + \frac{\beta \log\left(2^{\delta} - 1\right)}{\log(19)}$$

where x is similarly the centre of the length class and estimable parameters within CASAL are a_{50}, a_{to95}, and δ. Selectivity and maturity ogives were fitted within the model.

2.2 Biological inputs, priors and assumptions

2.2.1 Recruitment

Little data are available on recruitment. Relative year class strengths were assumed to average 1.0 over all years of the model. In the initial model development (Cryer et al., 2005) lognormal priors on relative year class strengths were assumed, with mean 1.0 and c.v. 0.2. The sensitivity year class strength (YCS) variation is examined. The relationship between stock size and recruitment for scampi is unknown. However, New Zealand scampi have very low fecundity (in the order of tens to hundreds of eggs carried by each female), so very successful recruitment is probably not plausible at low abundance. Scampi enter the model partition as 1 year olds. The distribution of their sizes was assumed to be normally distributed with mean 10 mm OCL and c.v. of 0.4. It is unclear how much information the various commercial (2.3.6) and research trawl (2.4.3) length frequency distribution data provide on individual YCSs, and so the effect of smoothing YCS along a polynomial curve (with a vector smoothing penalty) was examined (reducing the parameters to be estimated).

2.2.2 Growth

Cryer & Stotter (1997, 1999) and Cryer & Oliver (2001) estimated growth from wild-tagged scampi in SCI 1 and aquarium-reared scampi from SCI 2, respectively. Recoveries and measurements of captive animals were made at a variety of intervals, so growth models were based on a modified length increment von Bertalanffy growth model, estimated using maximum likelihood, mixed effects models (after Francis 1988). Cryer & Oliver (2001) estimated g30 (expected annual increments for scampi of 30 mm OCL) at 5.01 mm for males and 5.26 mm for females, and estimated g50 at 1.05 mm for males and –0.82 mm for females. Because negative growth is disallowed in CASAL, equivalent values of g20 (6.99 mm for males and 8.30 mm for females) and g40 (3.03 mm for males and 2.22 mm for females) were interpolated. Growth variability (s_{min}) was specified as 1.5 mm after Cryer & Oliver (2001). Thus, growth of an animal of size class i is normally distributed with a mean of:

$$\mu = g_\alpha + \frac{\left(g_\beta - g_\alpha\right)\left(l_{ci} - l_\alpha\right)}{\left(l_\beta - l_\alpha\right)}$$

and standard deviation of:

$$\sigma = \max\left(c\mu, s_{\min}\right)$$

where l_i is the lower bound of the size class and $l_{ci} = (l_i + l_{i+1})/2$. The growth estimates of Cryer & Stotter (1999) and Cryer & Oliver (2001) and the derived estimates used in these models have several limitations. They were generated using a combination of data from tagged animals (in SCI 1) and aquarium-reared animals (from SCI 2 but maintained at 12 °C). The tag data may suffer from both catching (trawling) and tagging artefacts (which, if present, would both generally lead to some retardation of average growth), and very few small or medium-sized males were recaptured. Conversely, tagged scampi were released in about 400 m depth and would have been exposed to "normal" temperature of about 10 °C. Aquarium-reared scampi were collected from SCI 2 (again, by trawl), where average growth may be different than in SCI 1. A wider range of size classes of both males and females are included in this data set, although relatively few large males. The holding temperature of 12 °C may have resulted in accelerated growth, but little is known of the artefacts of holding scampi for long periods or of the artificial diet. Thus, both data sets have their limitations and, in addition, there is no consensus on the most appropriate means of combining the two. The von Bertalanffy growth curves are shown in Figure 7.

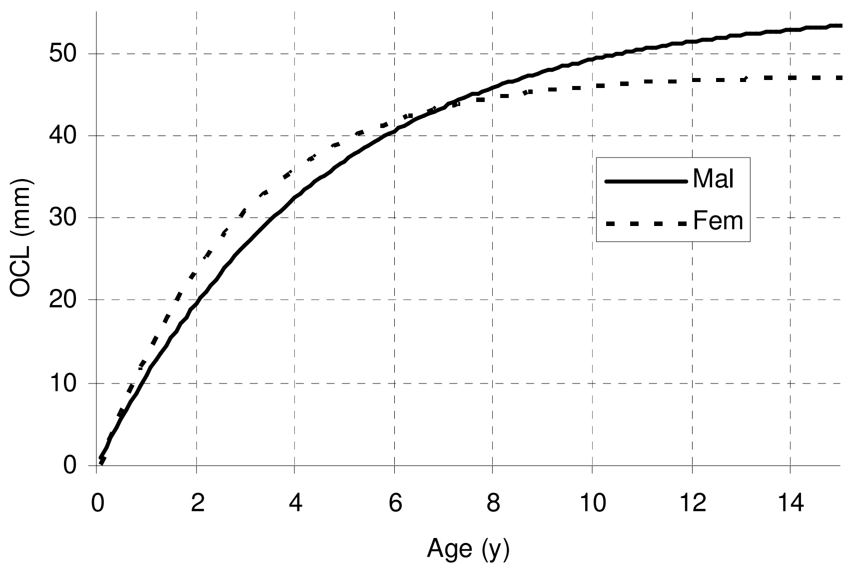

Figure 7: Age based von Bertalanffy growth curves calculated from GROTAG estimates of growth-at-length for male and females scampi assuming $t_0 = 0$ and a linear relationship between length and mean annual increment.

These growth parameters were estimated from relatively few animals (and in particular, very few small males). Three of the smaller females (about 30 mm OCL) had markedly large growth increments (8 – 13 mm), which may have contributed to the greater estimated growth rate for small females. Growth studies on *N. norvegicus* suggest males and female scampi grow along similar trajectories until maturity, following which, females grow at a similar rate (k) but to a lower L_∞ (Bailey & Chapman, 1983). This is likely to be a more realistic growth scenario than the one described in Figure 7. Implementing a maturity partition within CASAL allows for different growth parameters to be applied to immature and mature components of the population. Future model developments will investigate modelling growth within the assessment model, and allowing growth to vary after maturity, but as a first step, the sensitivity of the model to applying recalculated combined male and immature female (< 30 mm OCL at first capture) and mature female growth parameters is investigated. The growth parameters for the two groups were calculated from the original data set, using the same approach as Cryer & Oliver (2001), but with increments estimated for scampi of 20 mm and 40 mm OCL (to avoid the potential complication of negative increments). This reanalysis resulted in estimated g20 at 7.40 mm for males and immature females and 6.88 mm for mature females, and estimated g40 at 2.97 mm for males and immature females and 1.92 mm for mature females. As with the original model formulation (Cryer et al., 2005), growth variability (S_{min}) was specified as 1.5 mm after Cryer & Oliver (2001). The von Bertalanffy growth curves for the revised analysis are shown in Figure 8.

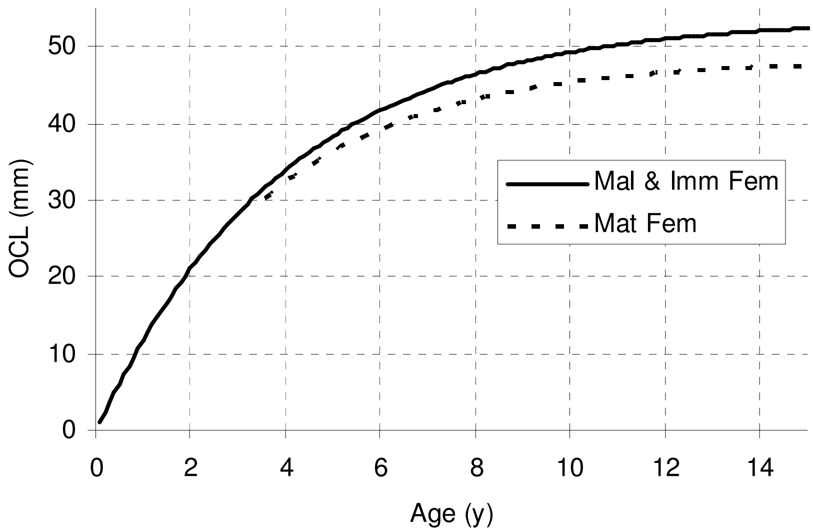

Figure 8: Age based von Bertalanffy growth curves calculated from GROTAG estimates of growth-at-length for combined male and immature female, and mature female scampi assuming t_0 = 0 and a linear relationship between length and mean annual increment.

2.2.3 Maturity

The proportion of females mature at each 1 mm size class have been recorded during all research surveys since 1993. Cryer et al (2005) used data from Cryer & Oliver (2001), pooled for females from SCIs 1 and 2, assuming internal gonad stages 2–5 to be mature, and stage 1 to be immature. New data are available (to 2006), and the analysis has been revised (Figure 9). Data were analysed for SCI 1 and SCI 2 separately, but the proportions mature at length were not significantly different between SCI (Kolmogorov-Smirov test, P=0.1353), and the data were therefore pooled. No data are available for the maturity of male scampi, so their maturity ogive was assumed identical to that of females, although studies on *N. norvegicus* have suggested that male maturity may occur at a larger size (although possibly the same age) than females (Tuck et al., 2000). Maturity is not considered to be a part of the model partition, but proportions mature were fitted within the model based on a logistic ogive with a binomial likelihood (Bull et al. 2004). Analysis of the proportion mature data, modelled as a function of length within a GAM framework, with a quasi distribution of errors and a logit link (McCullagh & Nelder, 1989),

$$P.mature = a + b * Length$$

which equates to the logistic model. The model was weighted by the number measured at each length. After obtaining estimates for the parameters *a* and *b*, the length at which 50% are mature (L50) was calculated from:

$$L_{50} = -\frac{a}{b}$$

The L50 estimate for the pooled SCI 1 and SCI 2 data was 29.7 mm, with a selection range a_{25} to a_{75} of 5.3mm.

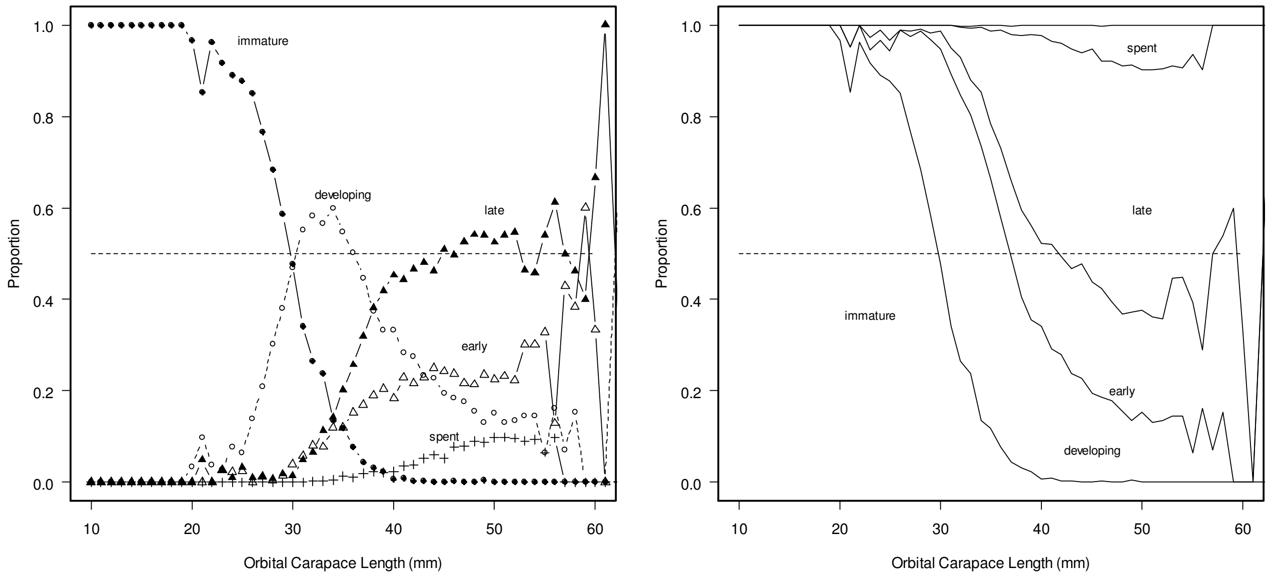

Figure 9: Proportions of female scampi having various developmental stages of internal ovaries. Left panel shows proportions of each stage separately, right panel shows combined proportions. Aggregated data from research voyages in SCI 1 & 2.

In implementation of the maturity partition, a logistic ogive was specified for maturation, with values for a_{50} of 30 mm, a_{to95} of 7 mm (as consistently estimated from other fits of the model).

2.2.4 Natural mortality

The instantaneous rate of natural mortality, M, has not been estimated directly for any scampi species, but Cryer & Stotter (1999) used a correlative method (after Pauly 1980, Charnov et al. 1993) based on their estimate of the K parameter from a von Bertalanffy growth curve. Based on this rough-and-ready estimate (Figure 10), Cryer et al. (2005) placed a log-normally distributed prior on M of 0.2 and tested c.v.s of 0.2, 0.4, and 0.8 with little effect on the behaviour of the model. Morizur (1982) used length distributions from "quasi-unexploited" stocks of *N. norvegicus* to obtain estimates of annual M of 0.2 to 0.3. The values most commonly assumed for assessment of *Nephrops* stocks in the Atlantic is 0.3 for males and immature females, and 0.2 applied for mature females, on the basis of their considerably reduced burrow emergence (and assumed mortality from fish predation) while ovigerous. Insufficient data is currently available to determine whether such a consideration would be appropriate for *M. challengeri*.

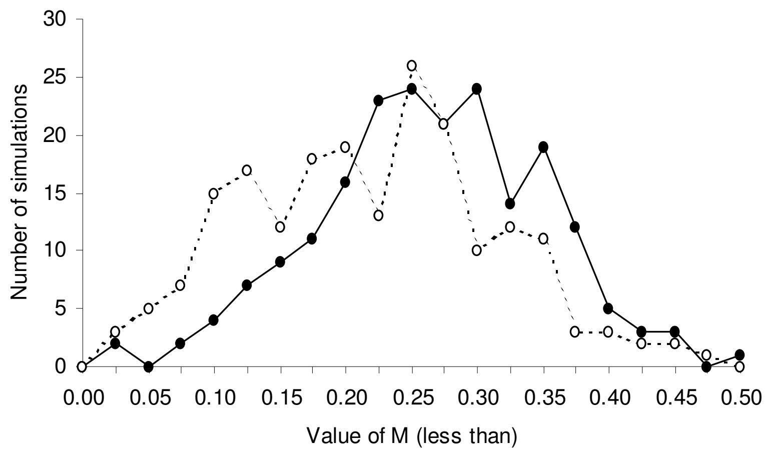

Figure 10: (after Cryer & Stotter 1999): Frequency distributions, from 200 bootstrap replicates, of the estimated rate of natural mortality, *M*, based on Charnov et al.'s (1993) regression of *M* on the von Bertalanffy *K*. Solid lines with solid circles represent the analysis using Ricker's (1975) method, while dashed lines and open circles indicate the analysis using the method of Francis (1988).

2.3 Catch data

2.3.1 Commercial catch

Scampi trawlers have recorded tow-by-tow information on Trawl Catch, Effort, and Processing Returns (TCEPR) since 1988–89. Catch by year was taken from Ministry of Fisheries Science Group (2006), and apportioned between the early and late seasons (October to December and January to September) in proportion to the sum of estimated catches on TCEPRs for those months. For the modelled area, commercial tows were included in the catch if they had a reported fishing depth between 300 and 500 m (both inclusive) and they finished within the model area (defined as research strata 302, 303, 402 and 403 used in trawl and photographic surveys in SCI 1, Figure 11, and research strata 702, 703, 802 and 803 used in trawl and photographic surveys in SCI 2, Figure 12) or if their estimated midpoint was within the model area. Overall, about 35% of the SCI 1's catch was estimated to have been taken outside the modelled area, mostly to the north, but this was not consistent between years (range 0–65%, Table 4), while about 2% of SCI 2's catch was taken outside that modelled area (range 0-20%, Table 5).

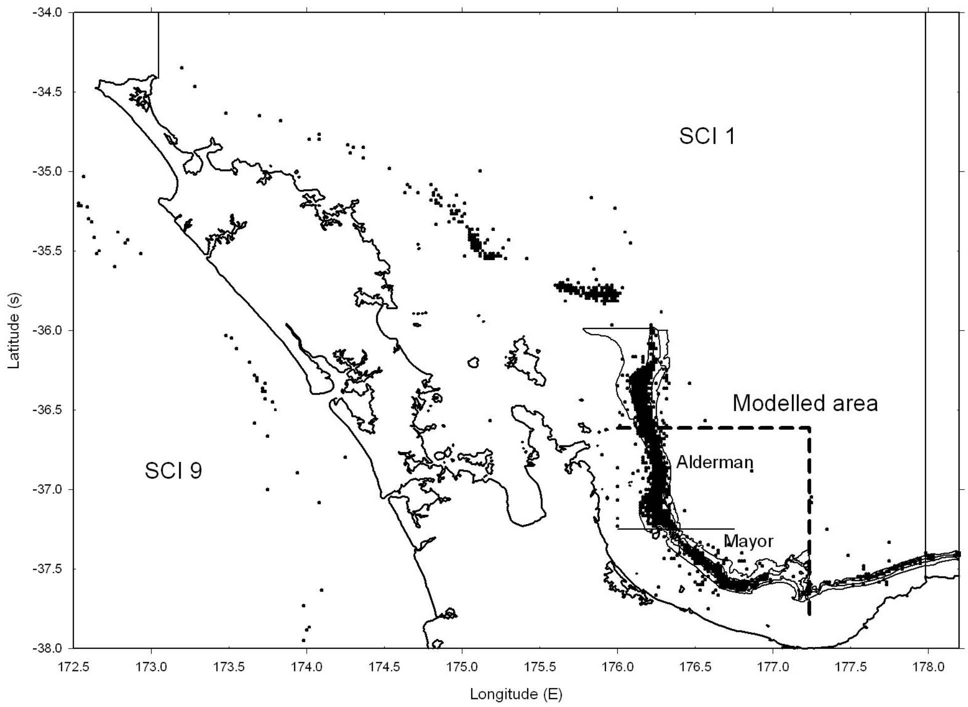

Figure 11: Locations of commercial tows for scampi in SCI 1 reported on TECPR forms to the end of the 2004-05 fishing year. The extent of the surveyed strata and the modelled area within this, are shown. Sub-areas within the modelled area are also indicated.

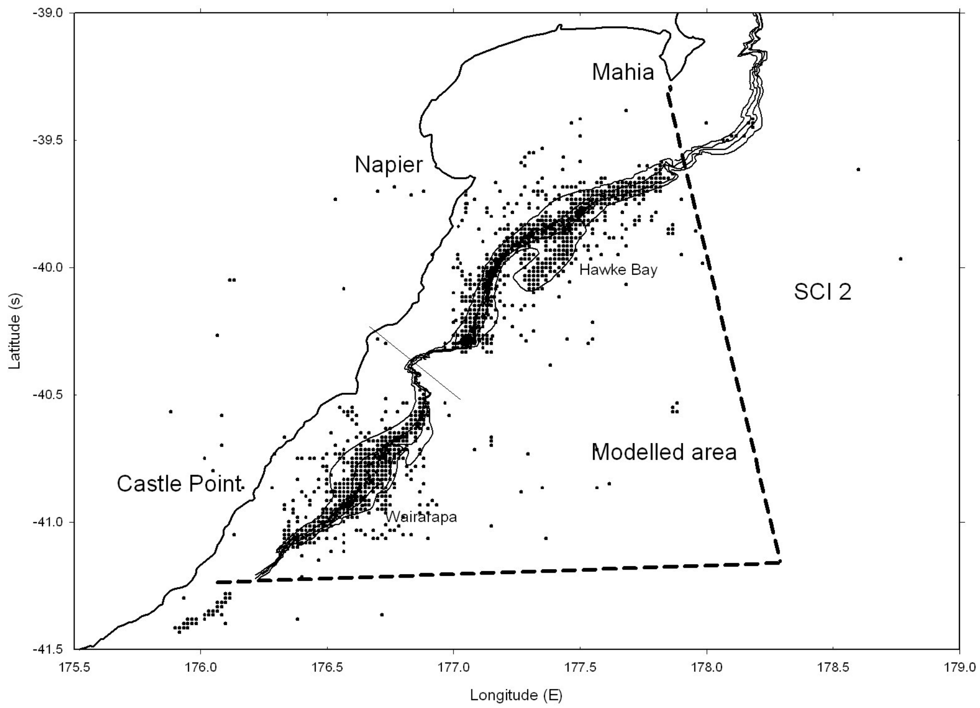

Figure 12: Locations of commercial tows for scampi in SCI 2 reported on TECPR forms to the end of the 2004-05 fishing year. The extent of the surveyed strata and the modelled area are shown. Sub-areas within the modelled area are also indicated.

Table 4: Estimated landed catch (t) from the whole of SCI 1 and within the modelled area in each time step.

		SCI 1 catch			Modelled area catch			Proportion	
Year	Step 1	Step 2	Total	Step 1	Step 2	Total	Step 1	Step 2	Total
1986	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-
1987	1.3	3.8	5.1	1.3	3.8	5.0	1.00	1.00	1.00
1988	3.8	11.3	15.1	3.8	11.3	15.0	1.00	1.00	1.00
1989	15.0	45.0	60.0	0.0	58.0	58.0	0.00	1.29	0.97
1990	31.4	72.6	104.0	29.7	68.7	98.4	0.95	0.95	0.95
1991	40.3	138.7	179.0	24.8	85.2	110.0	0.61	0.61	0.61
1992	73.1	58.9	132.0	55.3	44.6	99.9	0.76	0.76	0.76
1993	15.1	98.9	114.0	10.2	66.7	76.9	0.67	0.67	0.67
1994	59.1	55.9	115.0	38.1	36.0	74.1	0.64	0.64	0.64
1995	37.2	76.8	114.0	13.0	26.9	39.9	0.35	0.35	0.35
1996	41.6	75.4	117.0	22.2	40.3	62.5	0.53	0.53	0.53
1997	48.3	68.7	117.0	27.7	39.4	67.1	0.57	0.57	0.57
1998	64.0	43.0	107.0	36.1	24.3	60.4	0.56	0.56	0.56
1999	45.7	64.3	110.0	36.8	51.7	88.4	0.80	0.80	0.80
2000	12.6	111.4	124.0	7.3	64.8	72.1	0.58	0.58	0.58
2001	39.8	80.2	120.0	25.4	51.2	76.6	0.64	0.64	0.64
2002	116.2	7.8	124.0	63.4	4.3	67.6	0.55	0.55	0.55
2003	121.0	0.0	121.0	81.4	0.0	81.4	0.67	-	0.67
2004	120.0	0.0	120.0	76.4	0.0	76.4	0.64	-	0.64
2005	25.5	83.5	109.0	14.3	46.8	61.1	0.56	0.56	0.56
Total	910.9	1096.3	2007.2	566.9	723.8	1290.7	0.62	0.66	0.64

Table 5: Estimated landed catch (t) from the whole of SCI 2 and within the modelled area in each time step.

		SCI 1 catch			Modelled area catch			Proportion	
Year	Step 1	Step 2	Total	Step 1	Step 2	Total	Step 1	Step 2	Total
1986	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-
1987	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-
1988	1.5	3.5	5.0	1.5	3.5	5.0	1.00	1.00	1.00
1989	5.1	11.9	17.0	5.1	11.8	16.9	0.99	0.99	0.99
1990	9.6	128.4	138.0	9.5	128.3	137.9	1.00	1.00	1.00
1991	95.0	200.0	295.0	94.5	199.1	293.7	1.00	1.00	1.00
1992	75.9	145.1	221.0	75.7	144.8	220.5	1.00	1.00	1.00
1993	21.2	188.8	210.0	21.2	188.3	209.4	1.00	1.00	1.00
1994	17.6	226.4	244.0	17.6	225.9	243.5	1.00	1.00	1.00
1995	49.1	176.9	226.0	46.9	169.1	216.1	0.96	0.96	0.96
1996	88.5	141.5	230.0	88.3	141.3	229.6	1.00	1.00	1.00
1997	63.6	149.4	213.0	62.7	147.1	209.8	0.98	0.98	0.98
1998	104.9	119.1	224.0	102.9	116.7	219.6	0.98	0.98	0.98
1999	90.0	143.0	233.0	89.2	141.7	230.9	0.99	0.99	0.99
2000	76.3	116.7	193.0	75.5	115.3	190.8	0.99	0.99	0.99
2001	19.3	126.7	146.0	19.1	124.9	144.0	0.99	0.99	0.99
2002	23.8	223.2	247.0	23.1	216.3	239.4	0.97	0.97	0.97
2003	35.1	98.9	134.0	33.9	95.6	129.5	0.97	0.97	0.97
2004	0.0	64.0	64.0	0.0	63.4	63.4	0.99	0.99	0.99
2005	12.5	58.5	71.0	10.0	46.9	56.9	0.80	0.80	0.80
	789.1	2321.9	3111.0	776.7	2280.2	3056.9	0.98	0.98	0.98

2.3.2 Recreational catch

There is no known recreational catch of scampi and any such catch is ignored in the model.

2.3.3 Customary catch

There is no known customary catch of scampi and any such catch is ignored in the model.

2.3.4 Illegal catch

We have no information on illegal catches of scampi and they are ignored in the model.

2.3.5 Incidental mortality

We have no information on the incidental mortality cause by the trawl method or on discard mortality caused by the exclusion of any damaged and discarded animals from reported landings within the New Zealand scampi fishery. Both are assumed to be negligible (based on our experience of the fishery as well as the lack of relevant quantitative information) and are ignored in the model. Investigations in Europe suggest 25% survival of discarded animals (Sangster et al., 1997), and some data are also available on survival after escape from fishing gear (Wileman et al., 1999), although fishing conditions are quite different in New Zealand to those where the studies took place.

2.3.6 Length frequency of the commercial catch

Length frequency samples from the commercial catch have been taken by scientific observers since 1992 (e.g., see Hartill & Cryer 2000 for an extensive review). Estimates of the length-frequency (with associated c.v.s) of the commercial catch were derived using the NIWA catch-at-age software (Bull & Dunn 2002), using 1 mm (OCL) length classes by sex, weighting the proportions at length in each of two sub-areas within each modelled “core” area (Aldermen Islands and Mayor Island in SCI 1, Hawke Bay and Wairarapa in SCI 2) by the amount of catch estimated to have been taken from these areas using the estimated catches reported on TCEPR. The total numbers measured, numbers within the modelled area, and effective sample size are shown in Table 6 (SCI 1) and Table 7 (SCI 2). Length frequency distributions were calculated separately for the sexes and for each time step in the model and are shown in Figure 13 and Figure 14 for SCI 1 and Figure 16 to Figure 20 for SCI 2. Observer length sampling in 1992 was of total length (in subsequent years OCL was the standard measurement taken), and the data shown have been converted to OCL. The conversion process resulted in a very “jagged” length distribution, with certain converted OCL measurements never being observed, and therefore a three point moving average of proportion at length was used to smooth the data in this year. Preliminary analysis suggested this had minimal effect on the output of the base model, increasing B_0 by about 2%.

The observer sampling can be quite patchy in some areas (Hartill and Cryer, 2000), and the previous model development (Cryer et al., 2005) showed that the observed length frequency distributions did not match the fitted data well in some years and time steps, resulting in the recommendation that the representativeness of the available observer data be examined. The percentage distribution of scampi landings from SCI 1 by model year, time step and 50 m depth band are shown in Table 8. Over the history of the fishery, over 90% of landings have come from 350 m to 450 m depth. The depth distribution of observer sampling is shown in Table 9. While the observer sampling has concentrated on the core depth range of the fishery, sampling in some time periods has not matched the depth distribution of the fishery (particularly when observer sampling was only available from one depth band (i.e., 1993_1, 1994_2, 1996_1 and 2002_1).

The fishery in SCI 2 appears to be slightly shallower than in SCI 1, with almost 90 % of the landings coming from 300 m to 400 m depth (Table 10). More observer sampling data are available for SCI 2 than SCI 1, with only a few years and time periods missing data (Table 11), but as with SCI 1, the depth distribution of observer data does not always match the fishery well (i.e. 1993_1, 1998_2 and 2005_1).

For both areas, observer samples that were not considered to adequately represent the depth distribution of the fishery were excluded for the base model, although the sensitivity of the model to this data exclusion was examined.

Table 6: Actual number of scampi measured by observers in each time step of each year between 1990-91 and 2004-05 in SCI 1 and in the modelled area of the fishery, and the estimated effective sample size for assumed multinomial error structure.

			Step 1			Step 2
year	SCI 1	Core	Effective	SCI 1	Core	Effective
1991				10245	3863	1466
1992	1717	1615	706	1851		
1993	263	50	50			
1994				100	100	98
1995				2519		
1996	500	400	219	1754		
1997				1905	1169	468
1998	2096					
1999				2586	1887	581
2000				3891	1389	693
2001						
2002	2458	138	135			
2004	315					
2005				2113	506	273
Total	7349	2203	1110	26964	8914	3579

Table 7: Actual number of scampi measured by observers in each time step of each year between 1990-91 and 2004-05 in SCI 2 and in the modelled area of the fishery, and the estimated effective sample size for assumed multinomial error structure.

			Step 1			Step 2
year	SCI 2	Core	Effective	SCI 2	Core	Effective
1991				5821	5723	2306
1992	2336	1591	1045			
1993	100	100	96	2885	2885	931
1994				7537	6712	2461
1995				7556	6526	1967
1996	1784	1784	763	2006	2006	677
1997	4040	4040	1312	628	484	169
1998	896	896	327	300	300	236
1999	15531	15131	4527	4850	4850	1682
2000	7834	7834	2997	166	166	165
2001	9810	9810	2480	1550	1550	701
2002	4747	4747	2114	9940	7497	2613
2003	2078	2078	928	750	750	317
2004						
2005	630	630	321			
Total	49786	48641	16910	43989	39449	14225

Table 8: Percentage distribution of scampi landings, from SCI 1 by model year, time step and 50 m depth band.

	Depth band						
Year / step	200-249	250-299	300-349	350-399	400-449	450-499	500-550
1989_2			0.99%	29.10%	67.01%	2.75%	0.16%
1990_1			0.91%	56.83%	42.02%	0.24%	
1990_2			0.40%	74.54%	22.35%	2.71%	
1991_1				85.24%	14.40%	0.36%	
1991_2			1.55%	51.04%	41.94%	5.39%	0.08%
1992_1		0.19%	24.72%	53.02%	22.03%	0.05%	
1992_2			7.94%	68.87%	23.19%		
1993_1			6.10%	77.58%	14.91%	1.41%	
1993_2	1.18%	4.91%	19.64%	43.82%	29.36%	1.05%	0.04%
1994_1				72.46%	27.54%		
1994_2	0.43%	2.84%	16.49%	41.58%	34.48%	4.19%	
1995_1				72.11%	27.89%		
1995_2		0.02%	1.15%	53.79%	40.84%	4.20%	
1996_1				35.86%	63.17%	0.98%	
1996_2	0.36%		5.67%	19.71%	72.88%	1.37%	
1997_1				4.71%	87.90%	7.40%	
1997_2	1.38%	1.68%	1.27%	21.44%	73.68%	0.55%	
1998_1				45.65%	53.84%	0.51%	
1998_2			0.16%	56.52%	37.64%	5.68%	
1999_1	0.01%			51.97%	48.02%		
1999_2			0.63%	59.41%	39.37%	0.59%	0.01%
2000_1				39.99%	59.48%	0.53%	
2000_2			0.33%	55.06%	44.56%	0.05%	
2001_1				77.76%	22.24%		
2001_2			6.36%	71.86%	21.78%		
2002_1	0.48%	0.95%	16.89%	53.83%	26.86%	0.99%	
2002_2			9.03%	16.47%	74.50%		
2003_1		0.54%	15.86%	59.29%	24.31%		
2004_1		0.19%	29.20%	49.52%	21.09%		
2005_1			2.97%	58.69%	38.34%		
2005_2			1.01%	56.18%	42.76%		0.05%
Average	0.12%	0.37%	5.46%	52.06%	40.66%	1.32%	0.01%

Table 9: Percentage distribution of scampi catch from observer voyages, from SCI 1 by model year, time step and 50 m depth band (left table) and difference (where observer data is available) between percentage distribution in observer and landings data (right table).

					Difference between distributions			
Year/step	300-349 m	350-399 m	400-449 m	450-499 m	300-349 m	350-399 m	400-449 m	450-499 m
1991_2		72.11%	24.00%	3.89%		-21.08%	17.95%	1.50%
1992_1	29.07%	54.94%	15.99%		-4.35%	-1.92%	6.04%	
1993_1	100.00%				-93.90%			
1994_2		100.00%				-58.42%		
1996_1		100.00%				-64.14%		
1997_2			100.00%				-26.32%	
1999_2		82.01%	17.99%			-22.61%	21.38%	
2000_2		76.69%	23.31%			-21.63%	21.25%	
2002_1		100.00%				-46.17%		
2005_2		40.78%	59.22%			15.40%	-16.46%	

Preliminary tree regression analysis of all the length frequency data from observer trips in SCI 1 (presented to the SFAWG in June 2006) indicated evidence of spatial and temporal pattern in the median length of both males and females, suggesting stratification of the assessment model may be appropriate. This analysis has been repeated for samples from the modelled area, for each sex separately, with the following model:

$$haul\_median = area + month + depth$$

with area representing either the Alderman or Mayor sub-area of the modelled area, and the model being weighted by the square root of the scampi catch form each haul, using the R software library *rpart*. Regression trees were pruned to find the optimal tree using cross validation method.

Table 10: Percentage distribution of scampi landings, from SCI 2 by model year, time step and 50 m depth band.

Year / step	Depth band >250	250-299	300-349	350-399	400-449	450-499	>500
1989_2	0.06%	1.06%	94.97%	3.66%	0.25%		
1990_1		4.98%	64.07%	30.95%			
1990_2		0.25%	47.17%	50.01%	2.57%	0.01%	
1991_1	0.56%	6.53%	47.64%	45.01%	0.26%		
1991_2	0.38%	1.37%	52.52%	39.01%	6.47%	0.25%	
1992_1	0.09%	22.42%	67.38%	9.49%	0.61%		
1992_2		0.30%	28.93%	63.01%	7.60%	0.04%	0.12%
1993_1	1.57%		55.26%	30.10%	13.07%		
1993_2	0.08%	3.92%	62.89%	28.65%	4.25%	0.07%	0.14%
1994_1			57.84%	33.45%	8.71%		
1994_2	0.26%	2.74%	56.83%	34.99%	4.10%	0.83%	0.24%
1995_1			25.09%	68.27%	6.64%		
1995_2	0.16%	0.18%	45.21%	42.61%	9.16%	2.68%	
1996_1		0.58%	30.95%	49.09%	15.99%	3.40%	
1996_2		0.26%	34.72%	55.30%	7.37%	2.01%	0.33%
1997_1		1.06%	45.71%	41.69%	10.40%	1.14%	
1997_2		0.19%	31.68%	44.51%	23.09%	0.53%	
1998_1	0.42%	1.70%	44.42%	44.94%	7.80%	0.72%	
1998_2	0.32%	0.69%	48.31%	46.10%	4.47%	0.08%	0.03%
1999_1	0.26%	2.46%	38.67%	47.34%	9.92%	1.15%	0.20%
1999_2	0.66%	0.35%	43.05%	43.89%	11.65%	0.29%	0.11%
2000_1		0.12%	39.43%	48.07%	11.96%	0.43%	
2000_2		0.30%	43.74%	48.31%	6.58%	0.95%	0.11%
2001_1			44.25%	50.67%	4.29%	0.79%	
2001_2	0.20%	0.68%	49.24%	45.21%	4.39%	0.28%	
2002_1			27.10%	58.41%	5.21%	9.28%	
2002_2	0.17%	1.76%	52.17%	37.02%	8.60%	0.15%	0.13%
2003_1			43.47%	49.07%	7.46%		
2003_2	0.27%	0.29%	47.02%	43.67%	8.65%	0.09%	
2004_1					100.00%		
2004_2			28.16%	61.81%	9.32%	0.48%	0.23%
2005_1			24.89%	67.97%	7.14%		
2005_2		1.19%	24.03%	61.16%	12.99%	0.29%	0.35%
Average	0.18%	1.71%	45.46%	44.00%	7.84%	0.72%	0.08%

The optimal trees for SCI 1 are shown in Figure 15. Neither area or depth were main contributors to primary splits for either sex, suggesting that within the modelled area, further spatial stratification is not required. Both sexes showed an identical tree pattern, with the first split showing the largest median size observed in the first four months of the calendar year, and the second split dividing the smallest median size observed in the last two months of the year from observations earlier in the calendar year. The changes in median size observed through the year are likely to be a result of a combination of the entry of recruits into the fishery, and seasonal patterns in burrow emergence and hence availability to the fishery in relation to moult and reproductive patterns, and may warrant additional time steps in future model development.

A similar analysis was conducted for observer data from SCI 2. As with SCI 1, the modelled area for SCI 2 coincides with the surveyed area, covering a depth range from 300 to 500 m. However, the modelled area for SCI 2 is larger than that for SCI 1 (1,482 km^2 compared to 1,196 km^2), and extends over a greater latitudinal range. The optimal trees for SCI 2 are shown in Figure 21. These regression trees are considerably more complex than those for SCI 1 (Figure 15), which may reflect the greater number of observations available for SCI 2, and the greater geographical range over which the modelled area extends. Area is the main contributor to the first split for both sexes, with a smaller median size generally observed in Hawke Bay (denoted area 3 in the regression) than the Wairarapa area. Within area, both sexes show splits in relation to depth and month, with larger median sizes observed in deeper areas, and generally earlier in the year. Overall, these results suggest that further spatial (on the basis of both latitude and depth) and temporal stratification of the SCI 2 model should be investigated.

Table 11: Percentage distribution of scampi catch from observer voyages, from SCI 2 by model year, time step and 50 m depth band (left table) and difference (where observer data is available) between percentage distribution in observer and landings data (right table).

						Difference between distributions				
Year/step	250-299 m	300-349 m	350-399 m	400-449 m	450-499 m	250-299 m	300-349 m	350-399 m	400-449 m	450-499 m
1991_2			80.45%	19.55%				-41.44%	-13.08%	
1992_1		91.53%	8.47%				-24.15%	1.03%		
1993_1				100.00%					-86.93%	
1993_2		59.50%	35.66%	4.84%			3.39%	-7.01%	-0.59%	
1994_2	1.50%	80.11%	16.30%	2.08%		1.24%	-23.28%	18.69%	2.02%	
1995_2		38.36%	47.36%	9.98%			6.85%	-4.74%	-0.83%	-1.62%
1996_1		82.53%	17.47%		4.30%		-51.58%	31.62%		
1996_2		14.37%	79.91%	5.72%			20.35%	-24.61%	1.65%	
1997_1		75.84%	24.16%				-30.13%	17.53%		
1997_2		46.76%	53.24%				-15.08%	-8.73%		
1998_1			80.93%	19.07%				-35.99%	-11.27%	
1998_2				100.00%					-95.53%	
1999_1	2.17%	38.93%	42.26%	16.64%		0.29%	-0.26%	5.08%	-6.72%	
1999_2		6.87%	56.82%	36.31%			36.17%	-12.93%	-24.66%	
2000_1		33.71%	39.53%	25.35%	1.41%		5.72%	8.53%	-13.39%	-0.98%
2000_2		100.00%					-56.26%			
2001_1		47.78%	42.21%	10.01%			-3.53%	8.46%	-5.72%	
2001_2		60.33%	31.31%	8.36%			-11.10%	13.90%	-3.97%	
2002_1		29.49%	70.51%				-2.39%	-12.10%		
2002_2	0.79%	73.61%	25.59%			0.97%	-21.45%	11.42%		
2003_1		18.22%	74.14%	7.64%			25.25%	-25.06%	-0.18%	
2003_2			100.00%					-56.33%		
2005_1		100.00%					-75.97%			

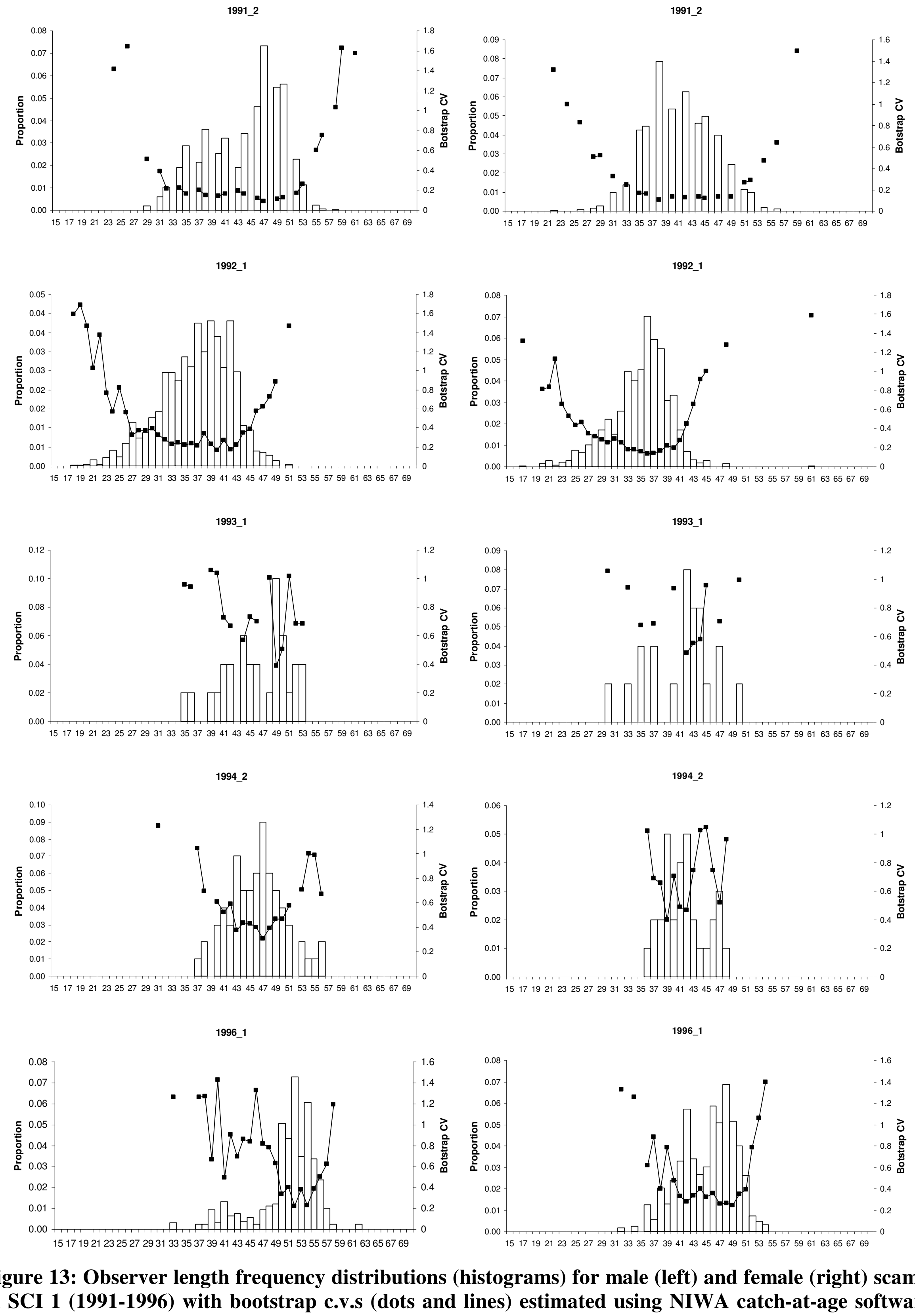

Figure 13: Observer length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 1 (1991-1996) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1991_2" (e.g.) denotes model year and time step.

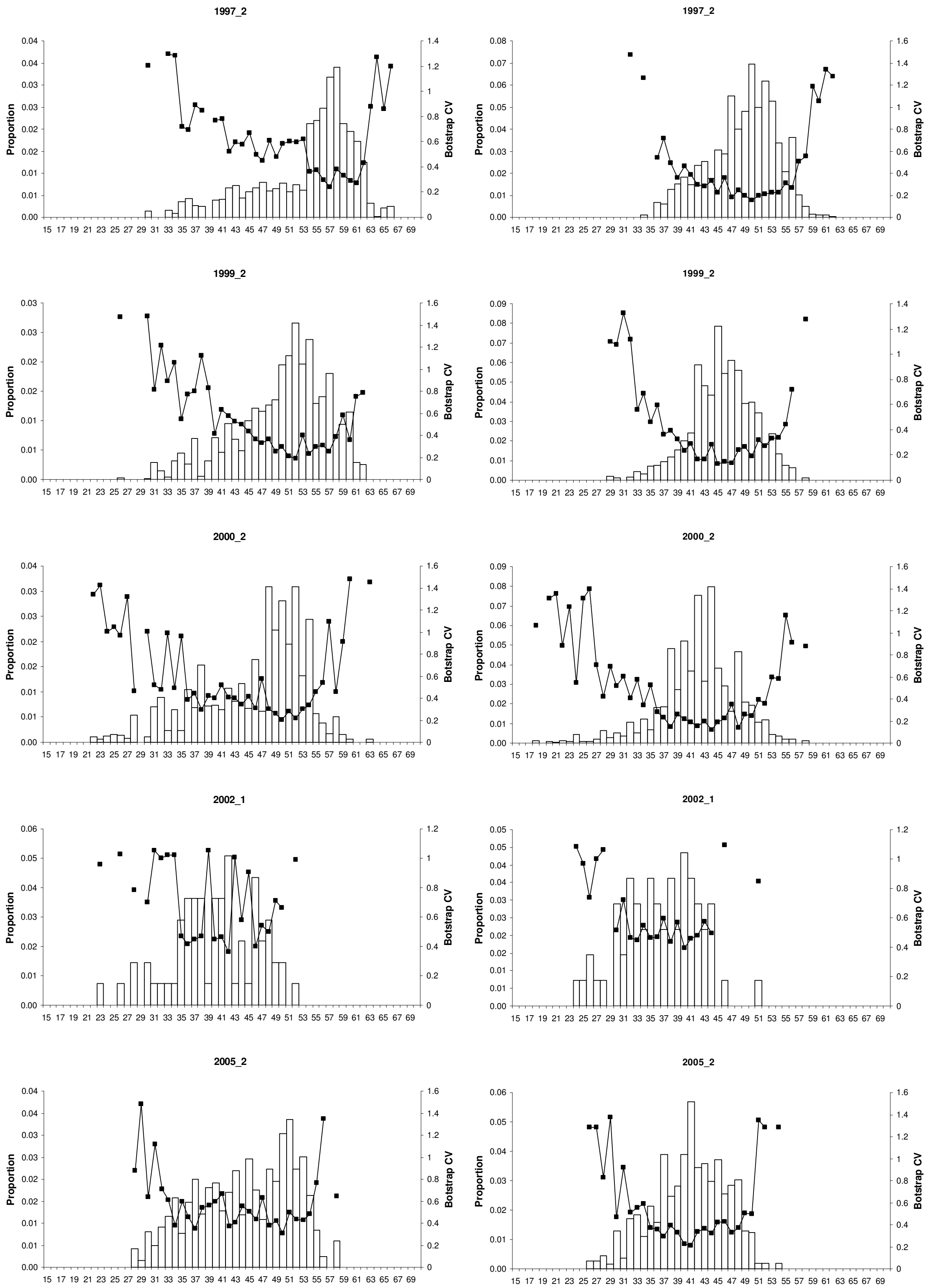

Figure 14: Observer length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 1 (1997-2005) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1997_2" (e.g.) denotes model year and time step.

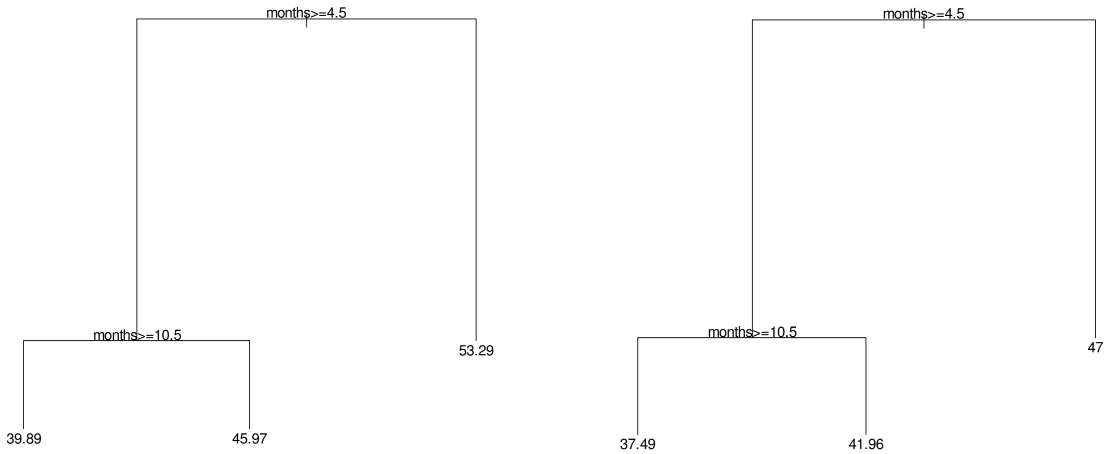

Figure 15: Optimal (pruned) regression trees for median length from observer samples for male (left) and female (right) scampi from SCI 1.

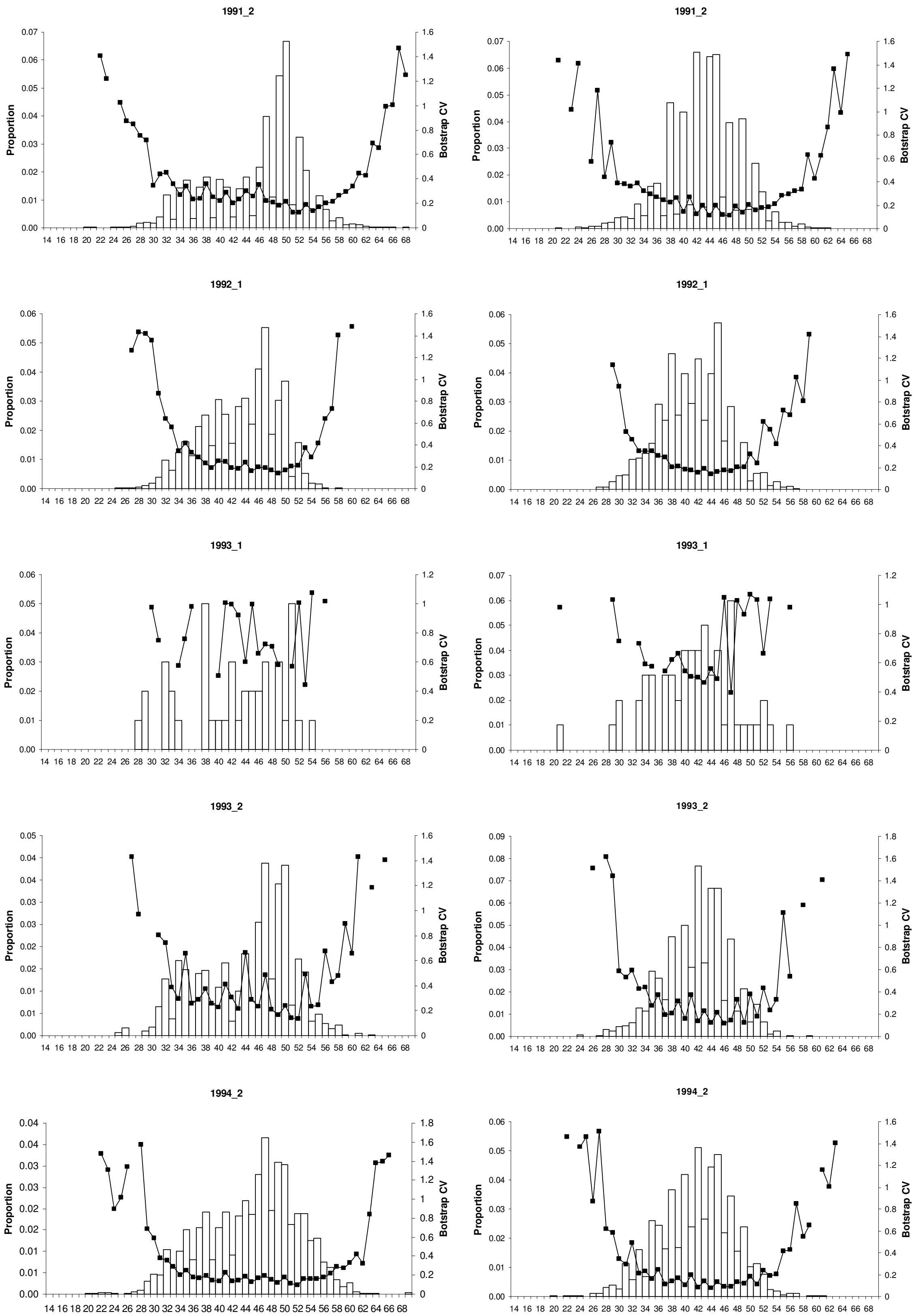

Figure 16: Observer length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 2 (1991-1994) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1991_2" (e.g.) denotes model year and time step.

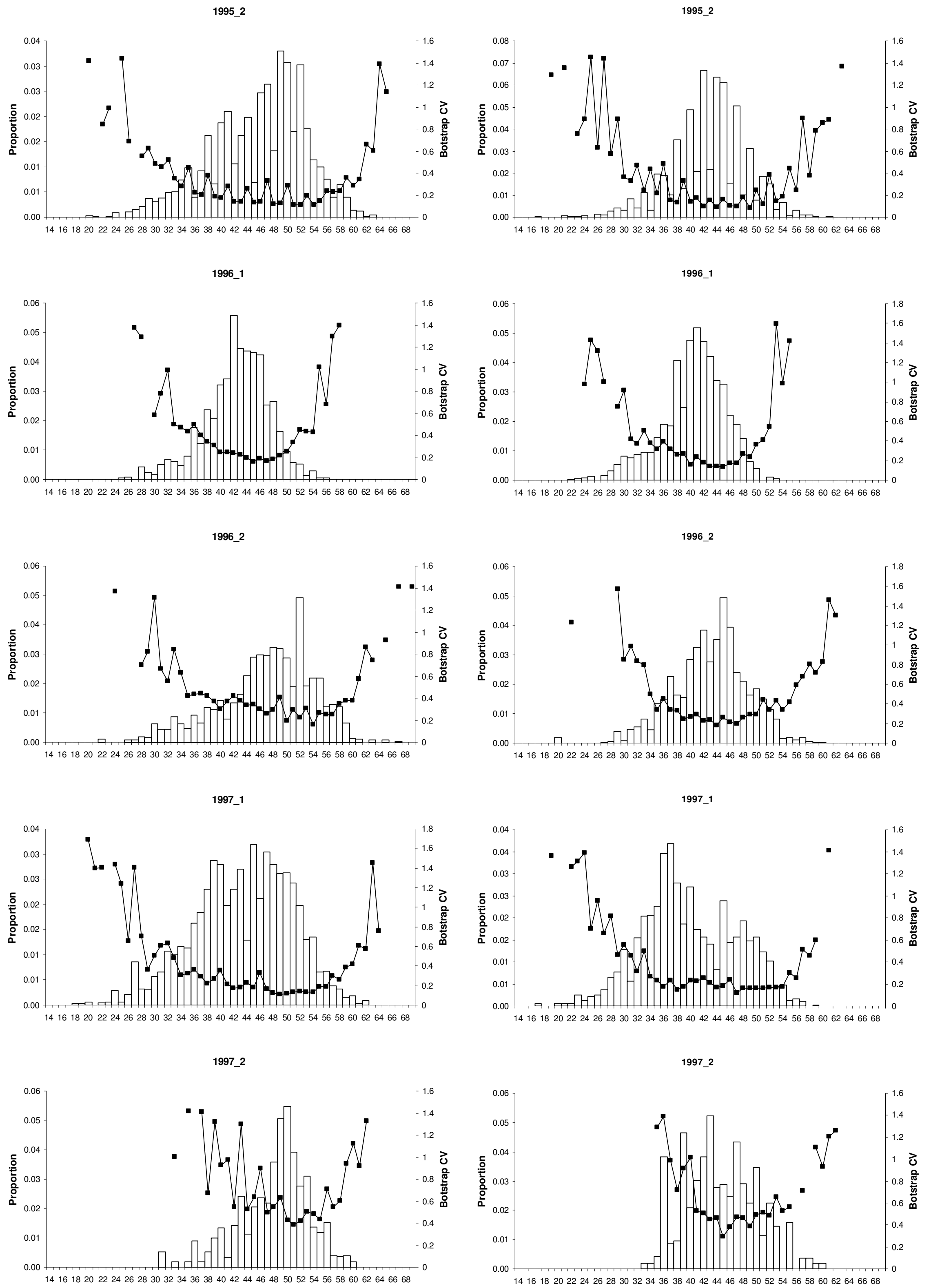

Figure 17: Observer length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 2 (1995-1997) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1995_2" (e.g.) denotes model year and time step.

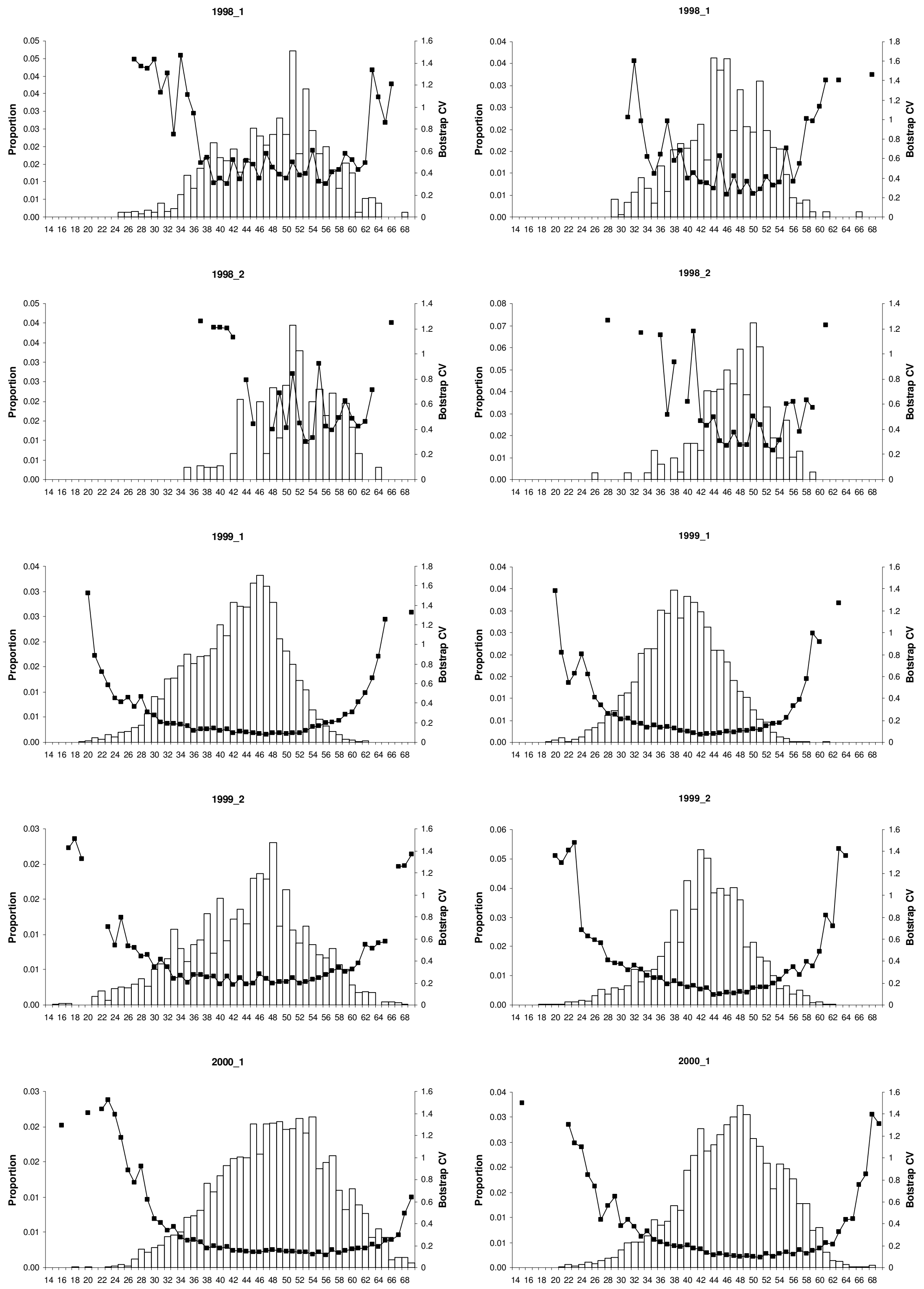

Figure 18: Observer length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 2 (1998-2000) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1998_2" (e.g.) denotes model year and time step.

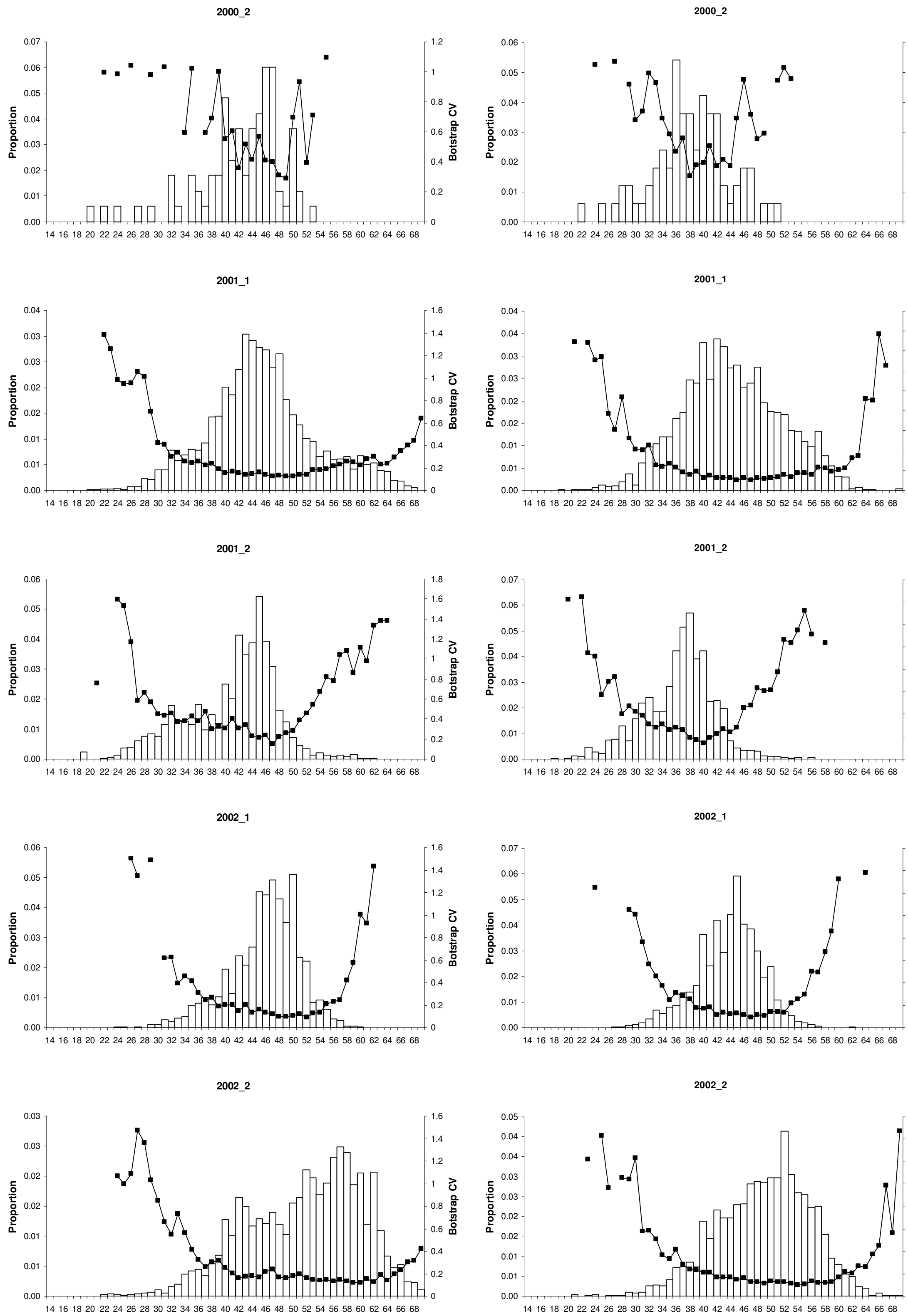

Figure 19: Observer length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 2 (2000-2002) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "2000_2" (e.g.) denotes model year and time step.

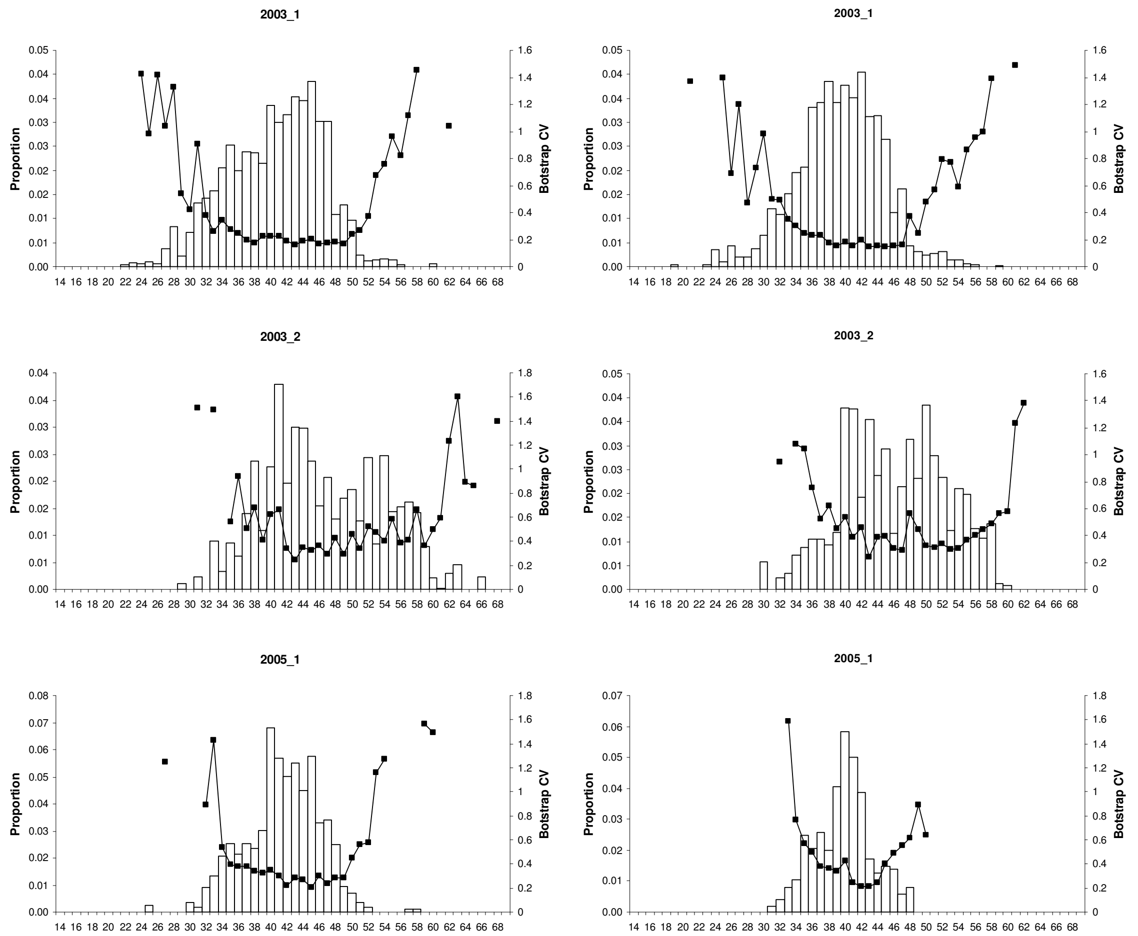

Figure 20: Observer length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 2 (2003-2005) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "2003_2" (e.g.) denotes model year and time step.

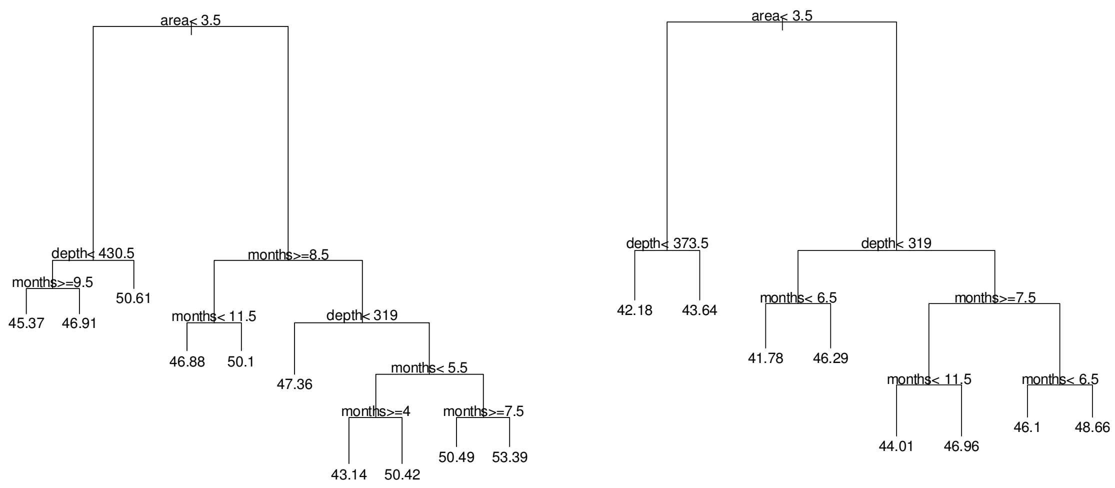

Figure 21: Optimal (pruned) regression trees for median length from observer samples for male (left) and female (right) scampi from SCI 2.

2.4 Resource surveys and other abundance information

2.4.1 Photographic estimates of abundance

Photographic surveys of SCI 1 and SCI 2 (e.g., Cryer et al., 2003; Tuck et al., 2006a) have been used to estimate the abundance of burrows thought to belong to scampi in 1998 and 2000 to 2003 (for SCI 1) and 2003 to 2006 (for SCI 2). Cryer et al. (2005) initially used the time series of burrow counts as an index of relative abundance and fitted to the index within the model using observed c.v.s (assumed log-normally distributed error). Following discussion within the SFAWG the abundance index was converted to a biomass index (using estimates of average animal size for each year, see below) and scaled to the whole of the core area. This meant that the estimated q for the photographic index of abundance could be interpreted as the proportion of model biomass explained by the burrows included in the analysis of photographic surveys (assuming 100% occupancy). This approach is continued here for comparison, but for most model runs the raised estimates of major burrow openings are used as a relative abundance index, with q interpreted as the proportion of model stock abundance explained by the burrows included in the analysis of photographic surveys (assuming 100% occupancy). Although the estimated length distributions from the size distributions of observed burrows (Figure 25 & Figure 26) are included in the model for estimation of photo survey selectivity, this approach avoids the need for conversion of two abundances (survey and model population) to biomasses for comparison. Cryer et al. (2005) assumed a log-normally distributed prior on *q-Photo* of 1.0, and tested c.v.s of 0.4, and 0.8 (with little obvious effect on the behaviour of the model). The sensitivity of the model to the prior on q-Photo is further examined, with an alternative estimate of q derived from the factors thought to contribute photo survey catchability, using the approach of Cordue (2001).

Estimation of *q-Photo*

The factors considered to affect *q-Photo* (when interpreted as the proportion of model stock abundance explained by the burrows included in the analysis of photographic surveys) are

- Spatial coverage of the survey compared to modelled area
- Major burrow opening occupancy rate
- Major burrow opening detection rate

with the three factor being multiplicative. It is assumed that *q-Photo* is constant over time and between strata and SCIs, although differences in underwater visibility and the occurrence of other burrowing species may have an influence. Two approaches have been considered, (1) assuming that the probability distribution of each of the factors is uniform and (2), using the mean occupancy and detection rates estimated for *Nephrops* and video surveys, along with the assumed bounds to estimate beta (since the distribution is bounded between 0 and 1) and gamma distributions for occupancy and detection, respectively. While in approach 1, the assumption of uniform factor distributions is perhaps unlikely (intermediate levels of occupancy and detection seem more likely than the extremes), approach 2 may put too much weight on data collected for a different (although similar) species, and a different survey approach (video counting of burrow systems rather than still photography counting of major entrances).

Spatial coverage determines a raising factor for converting the survey estimate to the modelled area estimate. The modelled area is defined by the survey strata, and therefore spatial coverage can be assumed to be 100%.

Burrow occupancy rate relates the numbers of burrows to the numbers of scampi in the survey area. Photo surveys for scampi in New Zealand are based on counts of major burrow openings. Although more than one scampi may inhabit a burrow system (as observed for *Nephrops*; Bell et al., 2006), we assume here that each individual would have its own major opening, and maximum occupancy is 1. Over a whole survey the bounds on occupancy rate are assumed to be 0.1 to 0.9. No studies to date have estimated scampi burrow occupancy in New Zealand. Marrs et al., (1996) analysed data sets from seven field programmes (from SCUBA diveable depth on the west coast of Scotland) and estimated burrow system occupancy to be 68%.

The burrow detection rate relates the numbers of burrows counted to the numbers of burrows present on the seabed. No studies to date have estimated scampi burrow detection rate in New Zealand. However, comparison of the canonical indices from individual readers in the analysis of reader bias (Tuck et al., 2006b) may provide an initial indication of the range of detection rates (comparing the least and most conservative readers). If it is assumed the most optimistic reader had a detection rate of 1 (100%), then the least optimistic would have a rate of 0.28 (only detecting 28% of burrows). If the least optimistic reader had a rate of 1 then the most optimistic reader would have a rate of 3.55 (estimating 3.55 times more burrows than actually present). At an individual image level detection rate may be zero, but the bounds on detection rate over a whole survey are assumed to be 0.1 to 3.55. Marrs et al., (1996) compared *Nephrops* burrow system counts from video survey tows and diver, and found that estimates were not significant different for experienced readers in relatively "simple" burrow communities, but that detection rates from video (video count / diver count) were 1.5 (counts overestimated by 50%) where other burrowing species made detection more complex.

The overall estimates of the prior distribution for *q-Photo* were obtained by sampling at random from the factor distributions in Table 12 (for approach 1) or Figure 23 (for approach 2) and combining values multiplicatively. This process was repeated 10 000 times. The resulting distributions were both approximately lognormal (although more so for approach 2) with mean and standard deviation (of $\log_e$ q) of -0.461 and 0.972 (Figure 22) for approach 1 (uniform factors), and -0.060 and 0.468 (Figure 23) for approach 2 (more informed factors). The poorer fit to the lognormal distribution of the q-Photo estimation in approach 1 may have lead to an underestimation of the mean and an overestimation of the standard deviation in the approximation (Figure 22).

Table 12: Estimated bounds on factors influencing *q-Photo*. The distribution of each of the factors was assumed to be uniform between the bounds. See text for details.

Factor	Lower bound	Upper bound
Spatial coverage	1	1
Occupancy rate	0.1	0.9
Detection rate	0.1	3.55
Product (overall bounds)	0.1	3.195

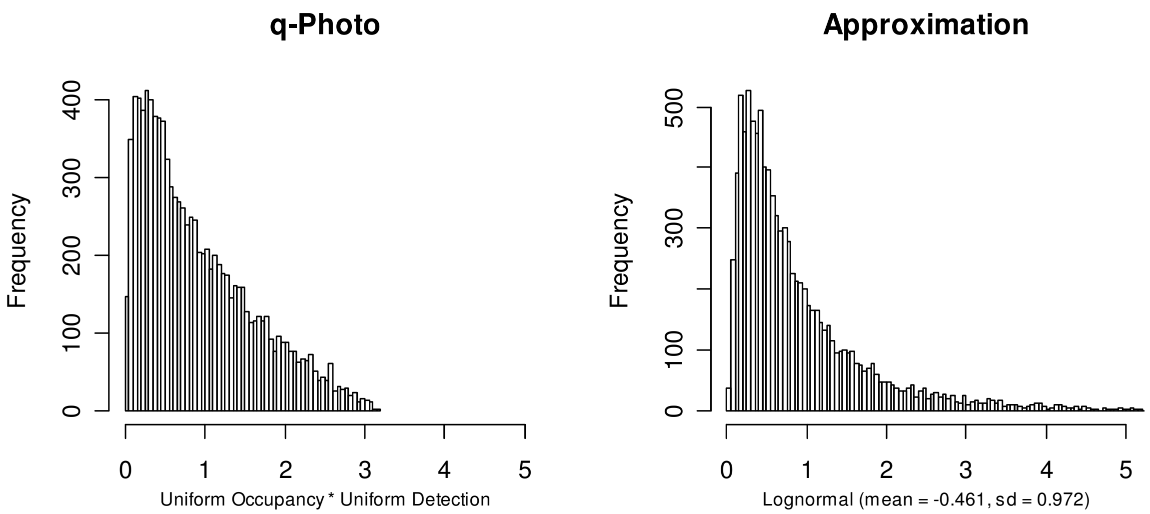

Figure 22: Estimated prior for *q-Photo* from uniform factors (left panel), and distribution derived by random sampling from a lognormal distribution with estimated lognormal parameters (right panel).

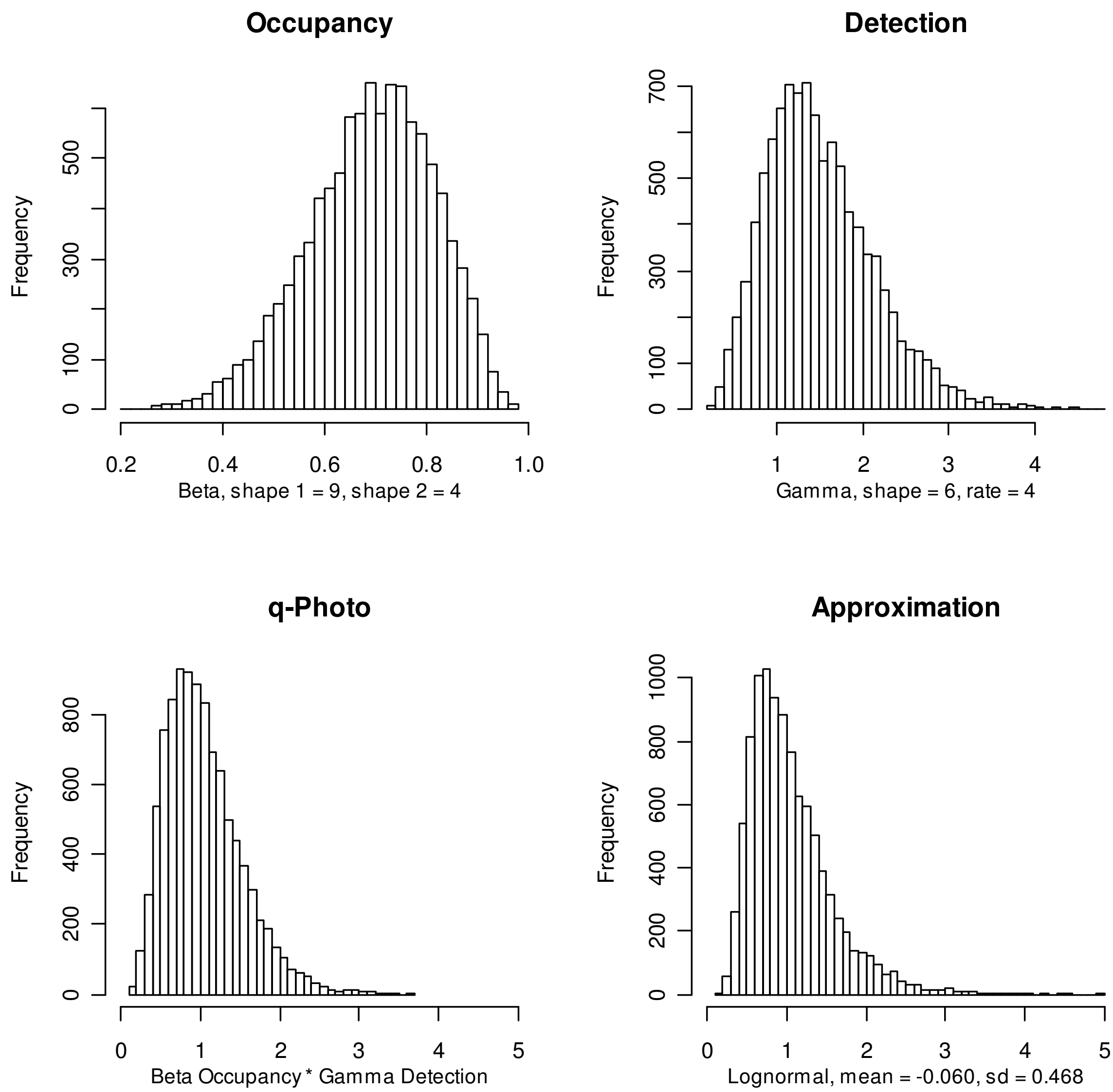

Figure 23: Estimated distributions for burrow occupancy and detection, prior for *q-Photo* multiplicatively from these factor distributions, and distribution derived by random sampling from a lognormal distribution with estimated lognormal parameters.

Estimating length frequency distribution from photographs

For both areas, length frequency distributions were estimated for the relative photographic abundance series. The widths of a large sample of major burrow openings were measured using *Didger 3.0* image analysis software. For SCI 1 these were converted to orbital carapace lengths using a regression of OCL on major opening width (Figure 24) developed using photographs of scampi clearly associated with burrows from SCI 1. Less scampi have been observed associated with burrows in SCI 2, and the data available were considered insufficient to provide a conversion relationship. Therefore the available data from SCI 2 was combined with that for SCI 1 to convert major opening width to orbital carapace lengths for SCI 2. The sample of burrows for measurement was selected on the basis that the image had been identified as having at least two probable burrow openings (to speed the process), and that two or more (of three) readers identified the particular burrow opening as likely to belong to scampi during routine screening to estimate relative biomass (e.g., Cryer et al. 2003). The relationship between OCL and burrow width seems mildly non-linear, so a variety of curvilinear regression models were fitted. The power relationship shown in Figure 24 (showing the SCI 1 data only) reproduced roughly the right amount of curvilinearity (by eye) and had the highest R^2 of the models applied. However, the estimated length frequency distributions were not very sensitive to the regression model applied. To estimate the c.v.s at length for each year, we used a bootstrap procedure, resampling with replacement from the original observations of burrow width, converting each observation to an estimated scampi size (in OCL) using the regression in Figure 24, using an error term sampled from a normal distribution fitted to the regression residuals. Compared with the length frequency distributions from trawl catches, this procedure gave very large c.v.s (Figure 25), but we think this is realistic given the uncertainties involved in generating a length frequency distribution from burrow sizes.

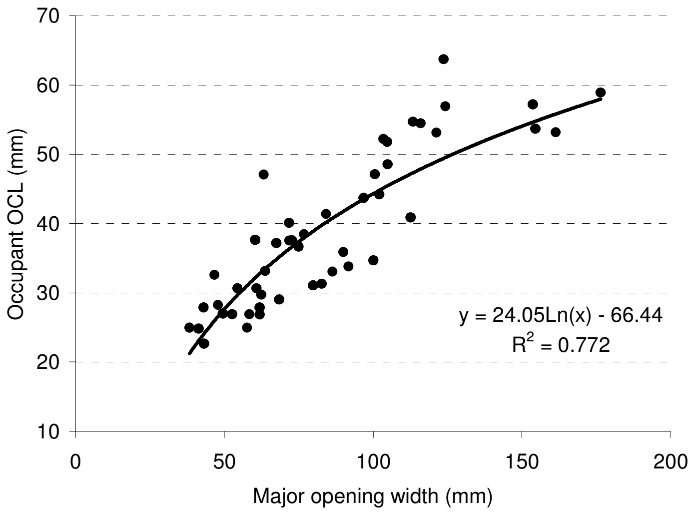

Figure 24: Estimated relationship between the width of a major burrow opening and the size of the occupying scampi (from photographs where animals were clearly associated with burrows) for SCI 1. Error in this regression was included in estimated length frequency distributions based on burrow sizes by bootstrapping.

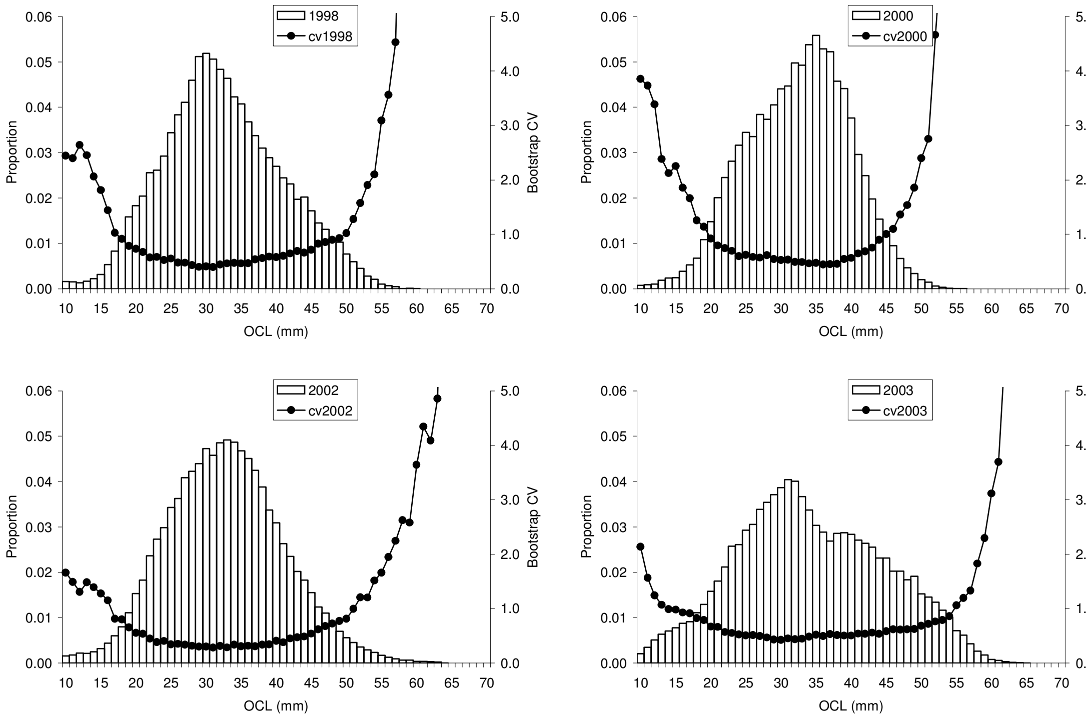

Figure 25: Bootstrapped length frequency distributions for SCI 1 (with CVs by 1 mm length class) estimated using estimates of major burrow opening widths from photographs and a regression of estimated occupant size on major opening width.

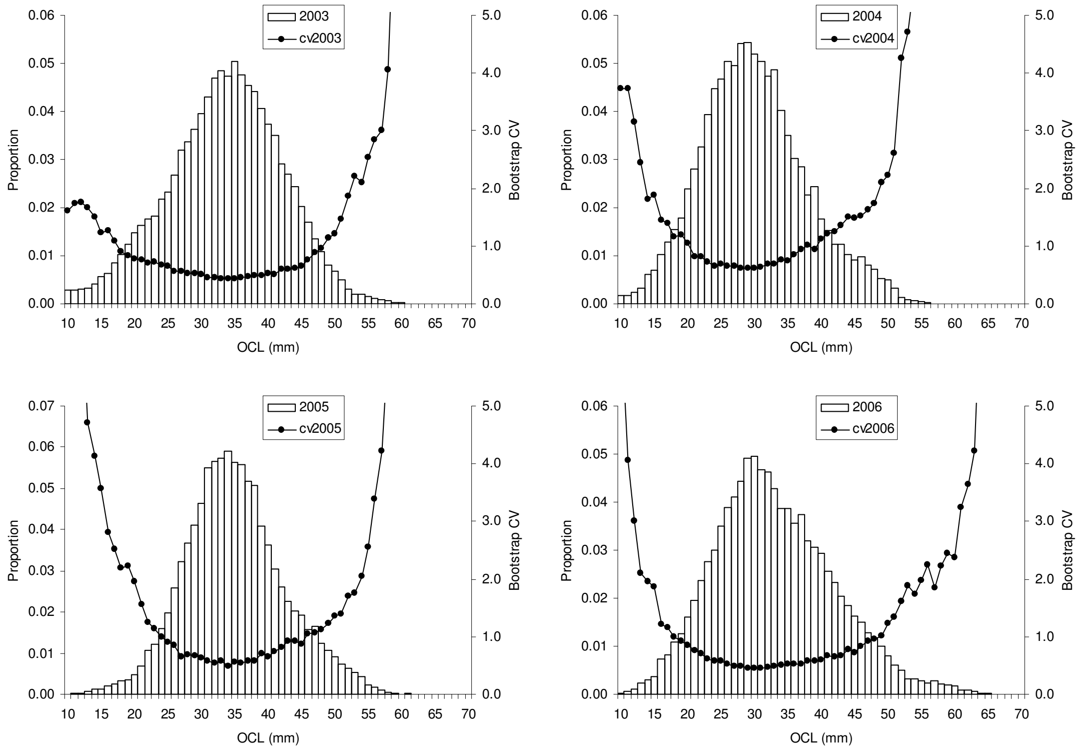

Figure 26: Bootstrapped length frequency distributions for SCI 2 (with CVs by 1 mm length class) estimated using estimates of major burrow opening widths from photographs and a regression of estimated occupant size on major opening width.

Extending photographic information to estimate biomass (where photo survey used as relative biomass index)

Estimating biomass from the photographic estimates of burrow abundance requires assumptions that all burrows (or some specified proportion) are occupied by a scampi, that the length frequency distribution of those scampi can be estimated from the dimensions of the burrows, and that the average weight of a scampi can be estimated from the length frequency distributions. The occupancy assumption remains untested, but the available data do suggest that burrow size increases with animal size (see Figure 24), permitting the estimation of population length frequency distribution from burrow sizes. Using the population length frequency distribution to estimate mean weight requires knowledge or an assumption about the population sex ratio, given that the length-weight relationship is steeper for males than for females and that males grow larger than females. For the purpose of this exercise, we assumed that the sex ratio (at length) in scampi caught by research trawling is indicative of that in the population (i.e., their selectivity ogives are the same). Selectivity at length is likely to be related to animal shape, and so this assumption is probably valid, although it is unclear whether emergence rates differ between the sexes. In *Nephrops*, female burrow emergence varies with reproductive state, and the sex ratio observed in catches may not reflect the sex ratio in the population (Bell et al., 2006). However, research trawl surveys have generally been conducted between January and March / April, which is likely to be the period when emergence is least affected by behavioural patterns (mature females between hatching one set of eggs and spawning the next). Amalgamating all research trawl length frequency distributions from each modelled area (Figure 27) suggests that the sex ratio is about even until about 35 mm OCL for SCI 1, but slightly lower at about 32 mm OCL for SCI 2. Cryer et al. (2005) assumed this point represented the size at maturity, although the pooled ovary stage data suggest size at 50% maturity may be closer to 30 mm (section 2.2.3). Above this size, females tend to predominate until a size of about 45 mm OCL in SCI 1 and 43 mm OCL in SCI 2. Scampi larger than this are increasingly likely to be males, although the rate of increase in likelihood appears to differ between areas. Scampi larger than 55 mm OCL in SCI 1 and 64 mm OCL in SCI 2 are almost certain to be males. This pattern, a predictable consequence of the fact that males grow larger than females, was used to weight predictions of mean weight-at-length for males and females, generating an estimate of population weight-at-length and, in conjunction with the estimated population length frequency distributions and the size of the modelled areas, an estimate of standing biomass for each year.

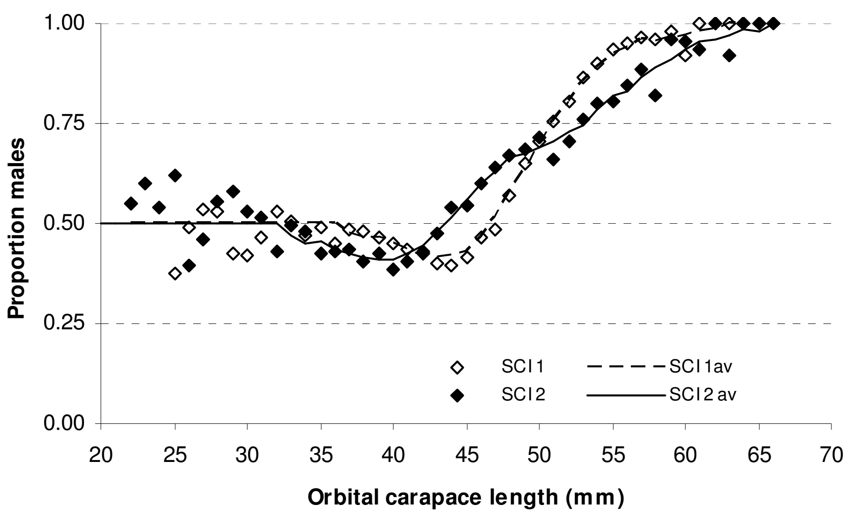

Figure 27: Proportion of males by size class averaged over all research trawl length frequency distributions in the modelled areas (areas calculated separately). The lines show a five-point moving

average mean (35 mm OCL and above) used to provide a weighting for the estimation of mean individual weight from animal and burrow sizes measured from photographs.

In SCI 1, there were more “large” burrows in 2002 and 2003 (suggesting the presence of scampi of 55–60 mm OCL, Figure 25), leading to higher estimates of mean weight in those years (25.76 g in 1998, 24.54 g in 2000, 26.26 g in 2002, and 33.01 g in 2003; no data were available for 2001 so we used the mean of estimates for 2001 and 2003). In turn, this leads to higher estimates of biomass relative to the number of burrows. The overall effect is to reduce the level of contrast in the time series and to remove the decline between 2002 and 2003 (Figure 28).

In SCI 2, there appeared to be a few particularly large burrows in 2006 (suggesting scampi of 60-65 mm OCL, Figure 26), and relatively more small burrows in 2004. The estimated mean weight of individuals varied between years (28.29 g in 2003, 20.38 g in 2004, 30.83g in 2005 and 27.77 g in 2006), and was used to estimate the biomass from burrow numbers (Figure 29). As with SCI 1, the effect of the changes in mean weight between years is to reduce the level of contrast in the time series, with the estimated biomass remaining stable at between 4200 and 4600 tonnes.

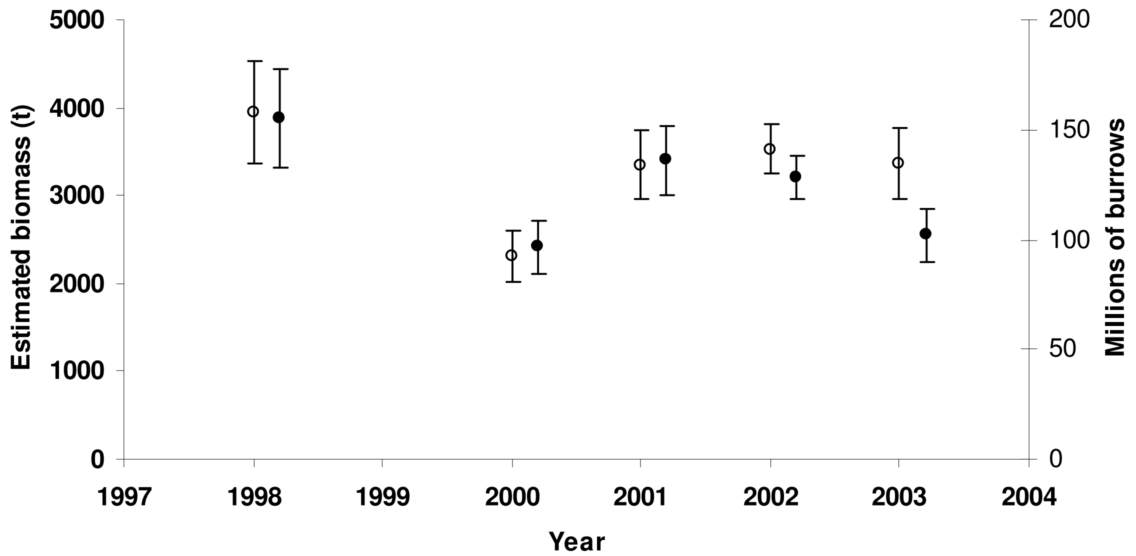

Figure 28: Comparison of abundance indices from photographic surveys. Solid circles show the estimated number of burrows within the modelled area of SCI 1 (strata 302, 303, 402 and 403), and the open circles show the estimated biomass (based on the number of burrows and an estimate of the average animal weight calculated using the size of the burrows in each year and a length weight regression). Data points are jittered for ease of viewing. Error bars indicate CVs.

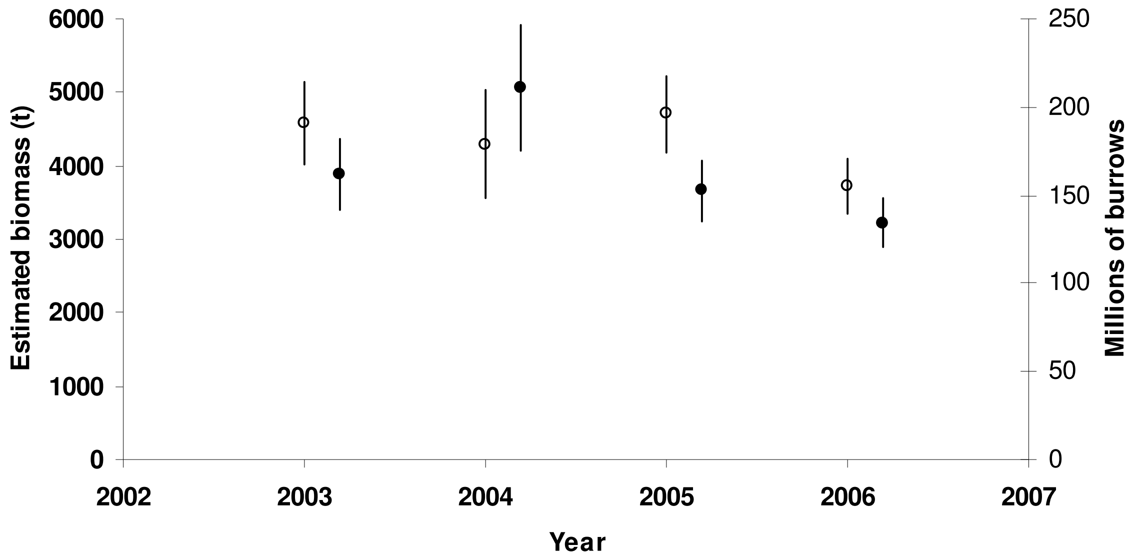

Figure 29: Comparison of abundance indices from photographic surveys. Solid circles show the estimated number of burrows within the modelled area of SCI 21 (strata 702, 703, 802 and 803), and the open circles show the estimated biomass (based on the number of burrows and an estimate of the average animal weight calculated using the size of the burrows in each year and a length weight regression). Data points are jittered for ease of viewing. Error bars indicate CVs.

2.4.2 Research trawl indices of relative abundance

Stratified random trawl surveys of scampi in SCIs 1 and 2, 200–600 m depth, were conducted in 1993, 1994, and 1995. Formal trawl surveys to estimate relative abundance were discontinued following this, because it was inferred from the results that catchability had varied among surveys. Nevertheless, research trawling has continued in both areas for a variety of other purposes (in support of a tagging programme to estimate growth in 1995 and 1996, to assess selectivity of research and commercial mesh sizes in 1996, and in support of photographic surveys since 1998). Identical gear has been used throughout (30 mm cod-end and 80 mm wings and belly), or we have selected only those tows where the standard gear was used (on gear selectivity trials). We assume these time series (Figure 30 for SCI 1 and Figure 31 for SCI 2) to be an index of relative abundance (with the caveat that catchability may vary among years and differences in diel timing and depths of tows may have affected the comparability of catch rates among years) and fitted to these indices within the model using observed c.v.s (assumed log-normally distributed).

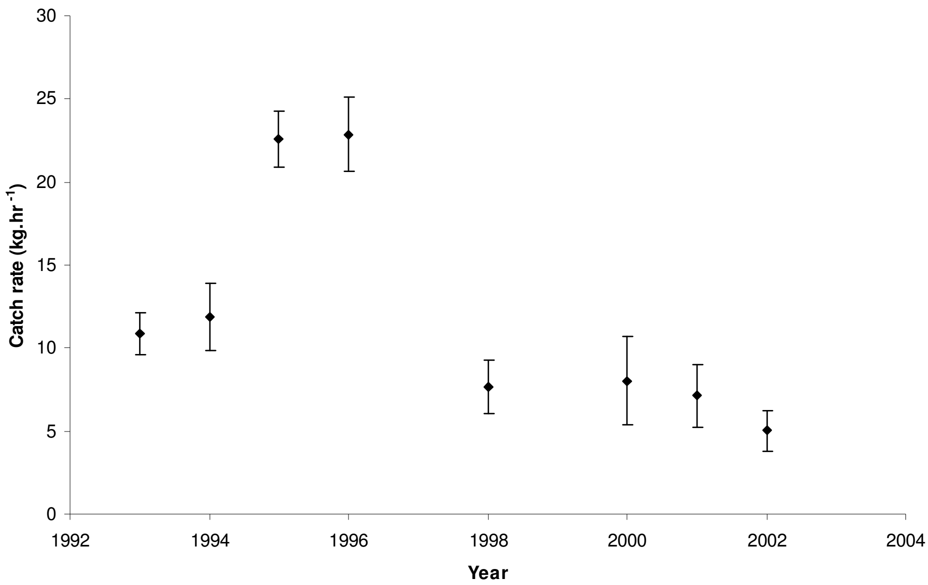

Figure 30: Mean catch rates of research trawling in SCI 1 (strata 302, 303, 402, and 403) between 1993 and 2002. The location and diel timing of trawling in 1995, 1996, and 1998 suggest that the former two are likely to be positively biased and the latter negatively biased relative to the rest of the time series.

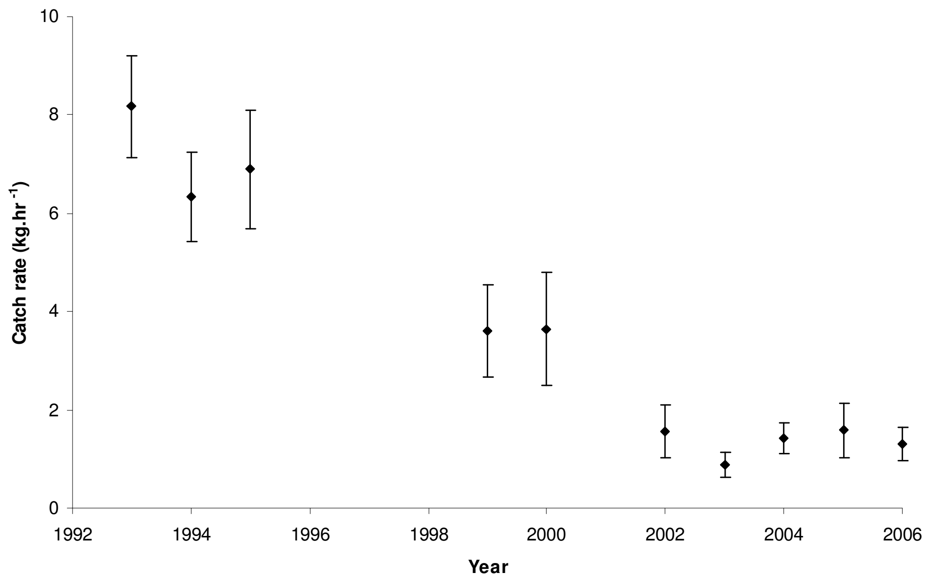

Figure 31: Mean catch rates of research trawling in SCI 2 (strata 702, 703, 802, and 803) between 1993 and 2006.

2.4.3 Length frequency distributions from research trawling

Length frequency samples from research trawling have been taken by scientific staff since 1993 in SCI 1 (Table 13) and SCI 2 (Table 14). Estimates of the length-frequency (with associated c.v.s) were derived using the NIWA catch-at-age software (Bull & Dunn 2002), using 1 mm (OCL) length classes by sex. These were calculated separately for the sexes and for each time step in the model, and are shown for SCI 1 in Figure 32 and Figure 33, and SCI 2 in Figure 34 and Figure 35.

Table 13: Actual number of scampi measured by research staff in each time step of year between 1990–91 and 2005–06 in SCI 1 and in the core area of the fishery, and the estimated effective sample size for assumed multinomial error structure. –, no research voyages, 1991 = 1990–91 fishing year, etc..

			Step 1			Step 2
year	SCI 1	Core	Effective	SCI 1	Core	Effective
1991						
1992						
1993				7 957	4 628	1 724
1994				6 334	3 945	1 349
1995				8 133	4 356	1 421
1996	3 474	3 474	1 562	1 128	1 128	424
1997	7 766	7 766	2 204			
1998				5 189	4 212	1 130
1999						
2000				1 652	1 054	412
2001				1 558	1 558	566
2002				2 268	2 268	607
2003						
2004						
2005						
2006						
Total	11 240	11 240	3 766	34 219	23 149	7 633

Table 14: Actual number of scampi measured by research staff in each time step of year between 1990–91 and 2005–06 in SCI 2 and in the core area of the fishery, and the estimated effective sample size for assumed multinomial error structure. –, no research voyages, 1991 = 1990–91 fishing year, etc..

			Step 1			Step 2
year	SCI 2	Core	Effective	SCI 2	Core	Effective
1991						
1992						
1993				3 809	3 384	1 675
1994				4 312	3 847	1 250
1995				5 185	4 611	1 514
1996						
1997						
1998						
1999				1 693	1 693	536
2000	1 472	1 462	450	824	807	477
2001						
2002						
2003				260	260	225
2004				588	564	308
2005				841	800	492
2006				613	594	272
Total	1 472	1 462	450	18 125	16 560	6 749

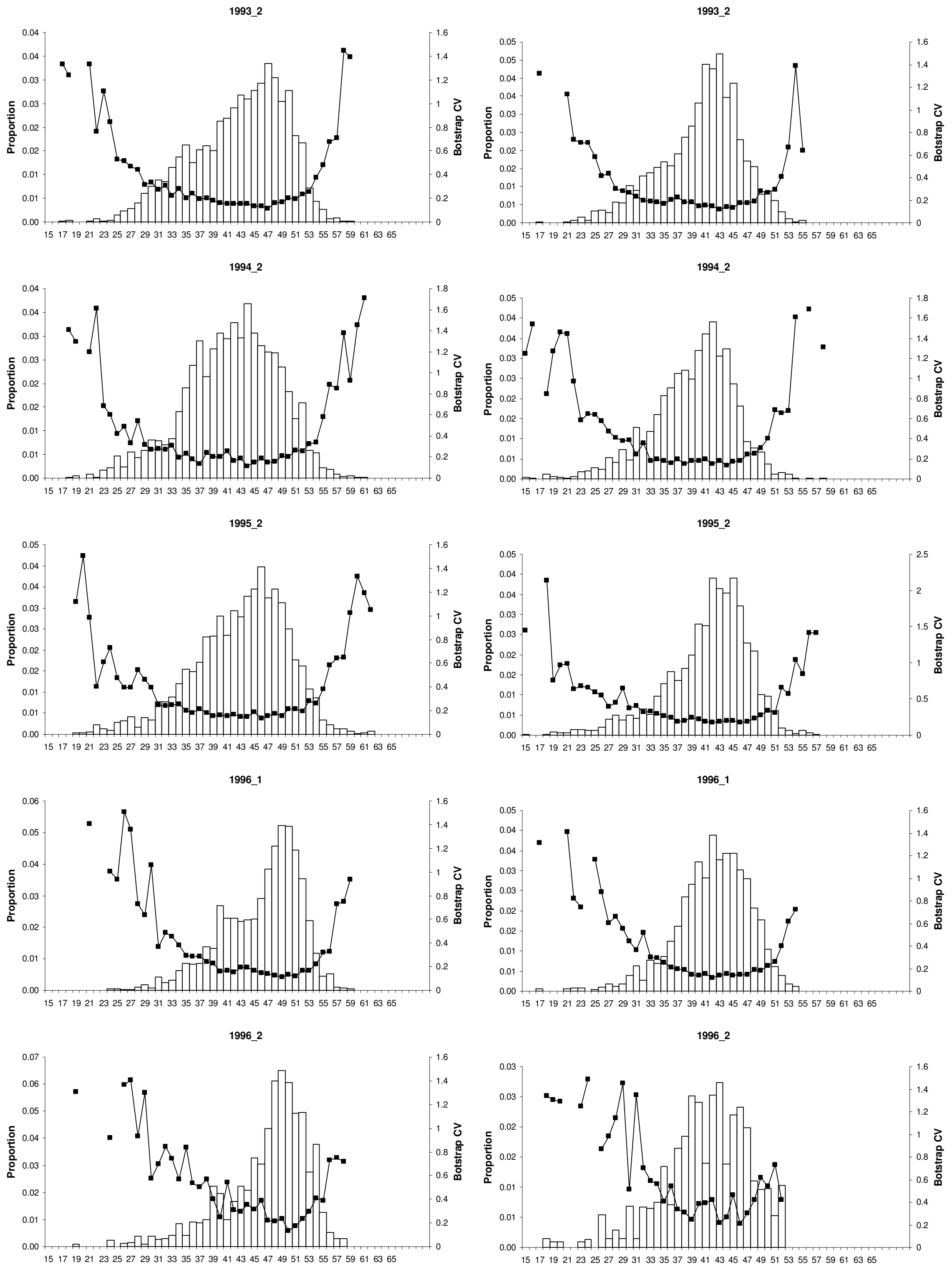

Figure 32: Research trawl length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 1 (1993-1996) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1993_2" (e.g.) denotes model year and time step.

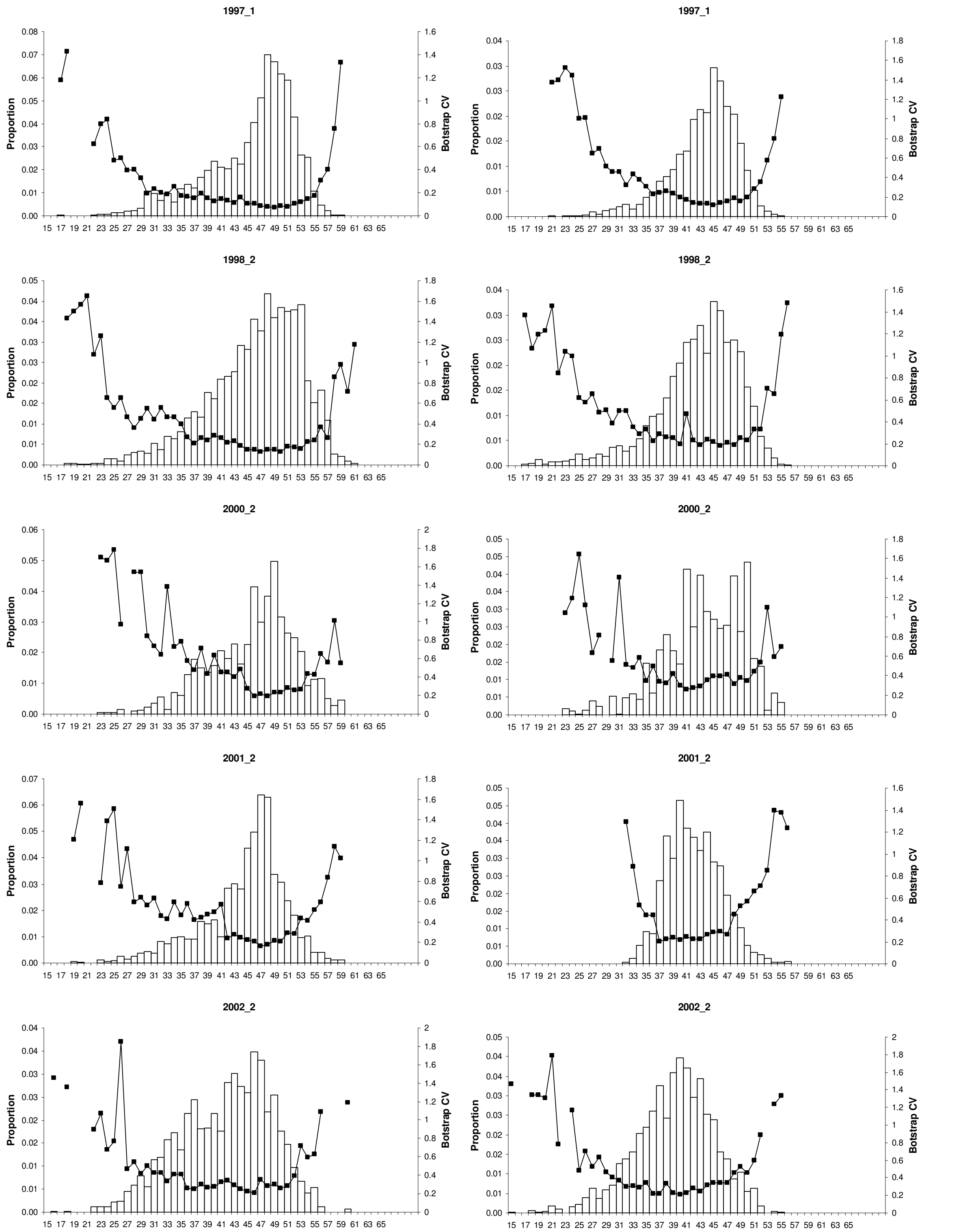

Figure 33: Research trawl length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 1 (1997-2002) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1997_2" (e.g.) denotes model year and time step.

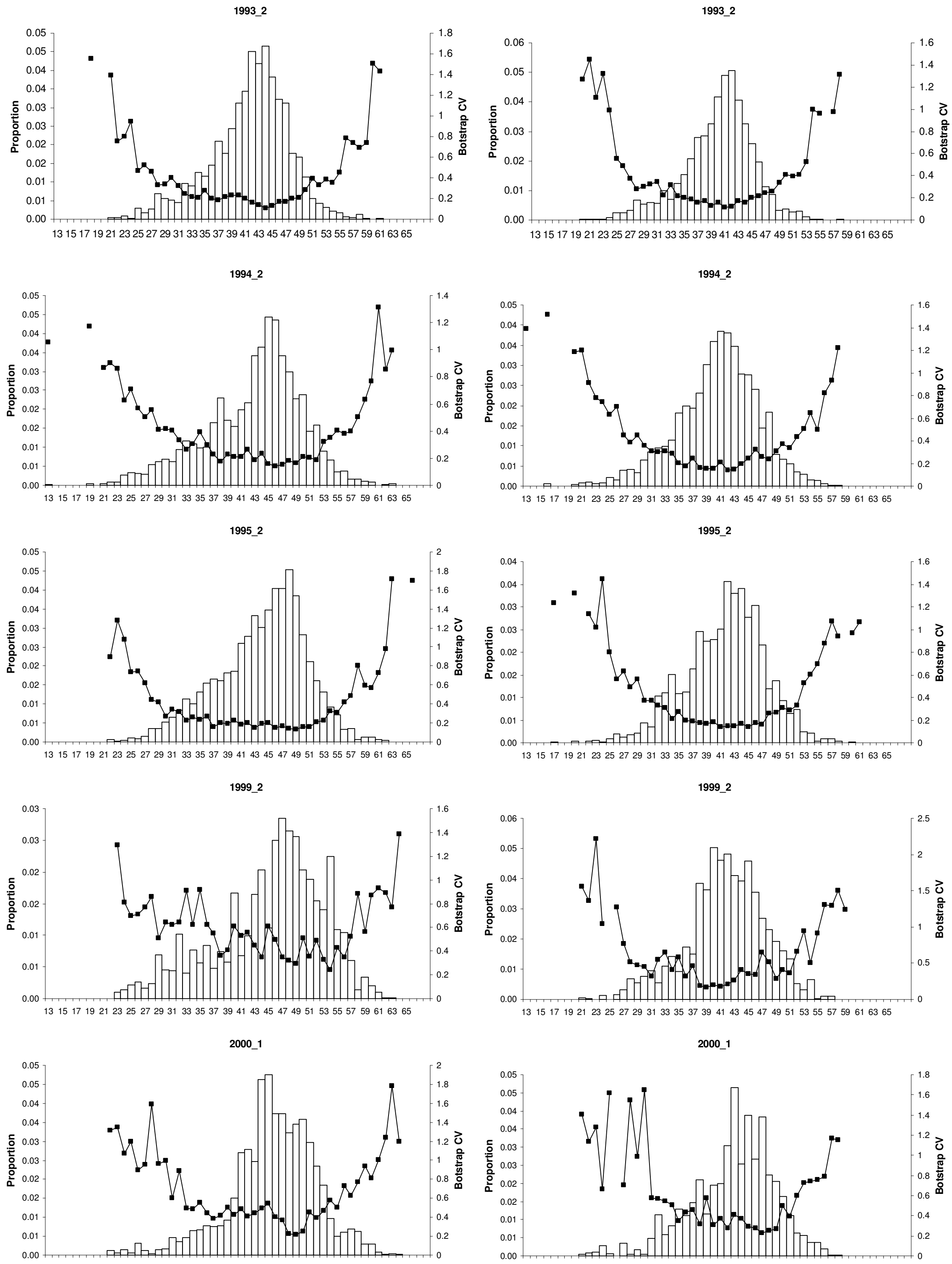

Figure 34: Research trawl length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 2 (1993-2000) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1993_2" (e.g.) denotes model year and time step.

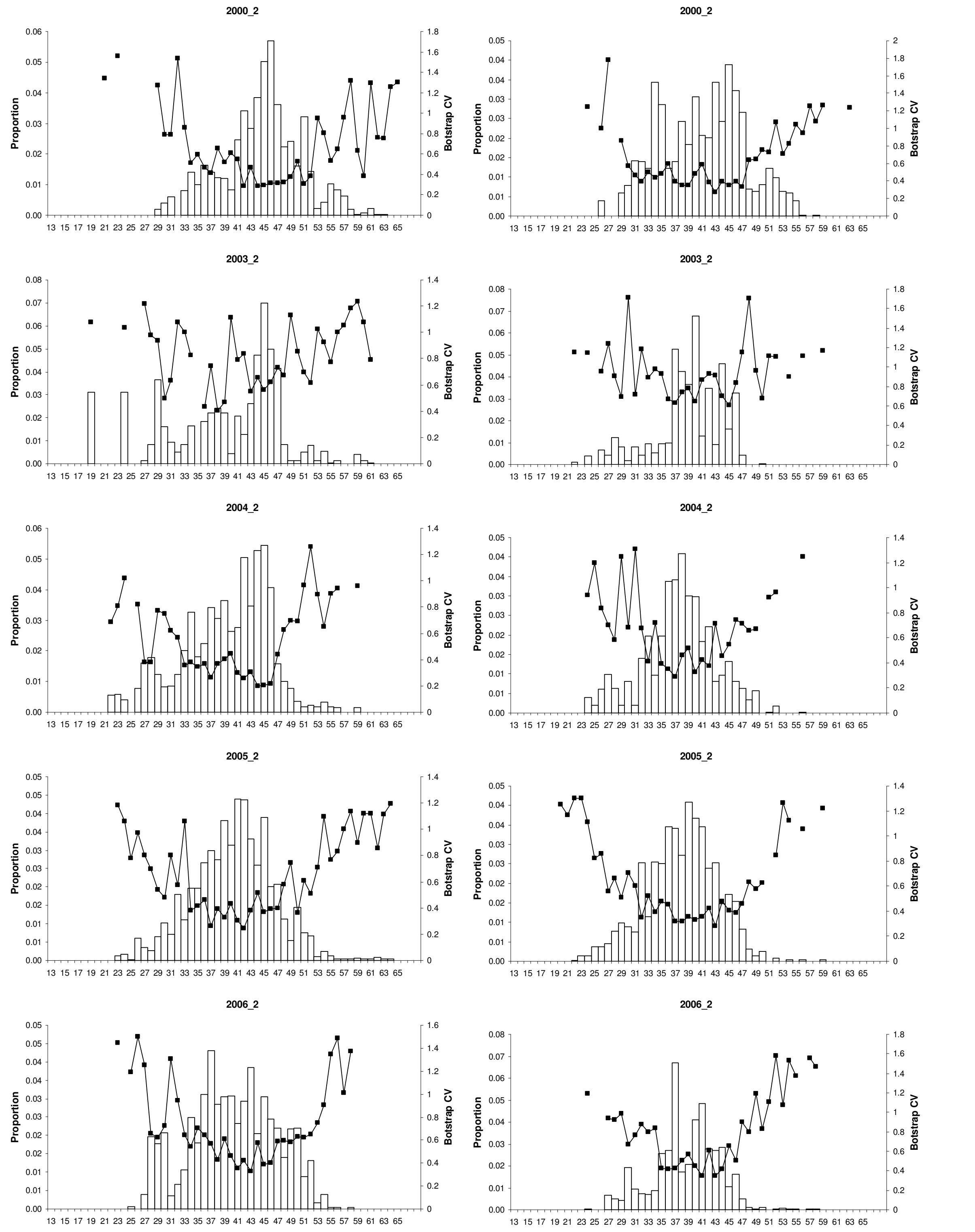

Figure 35: Research trawl length frequency distributions (histograms) for male (left) and female (right) scampi in SCI 2 (2000-2006) with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "2000_2" (e.g.) denotes model year and time step.

2.4.4 Commercial catch-effort indices of relative abundance

Cryer & Coburn (2000) calculated fully standardised indices for the SCI 1 and SCI 2 scampi fisheries up to the 1997–98 fishing year, although they found that the standardised index was highly correlated with much simpler unstandardised indices (total catch divided by total fishing effort), and these simpler indices have been used since (e.g., Hartill & Cryer 2004). We have adopted the "G3" time series of Hartill & Cryer (2004) (groomed data excluding obvious errors and zero catches of scampi and split between the two time steps in our model, Figure 36 for SCI 1 and Figure 37 for SCI 2) as an index of relative abundance and fitted to these within the model using nominal log-normal c.v.s. of 0.25. For SCI 1, CPUE in the modelled area was slightly higher than elsewhere during the mid 1990's, but has become very similar between the areas in recent years. For SCI 2, CPUE in the total and modelled area have been very similar throughout the series.

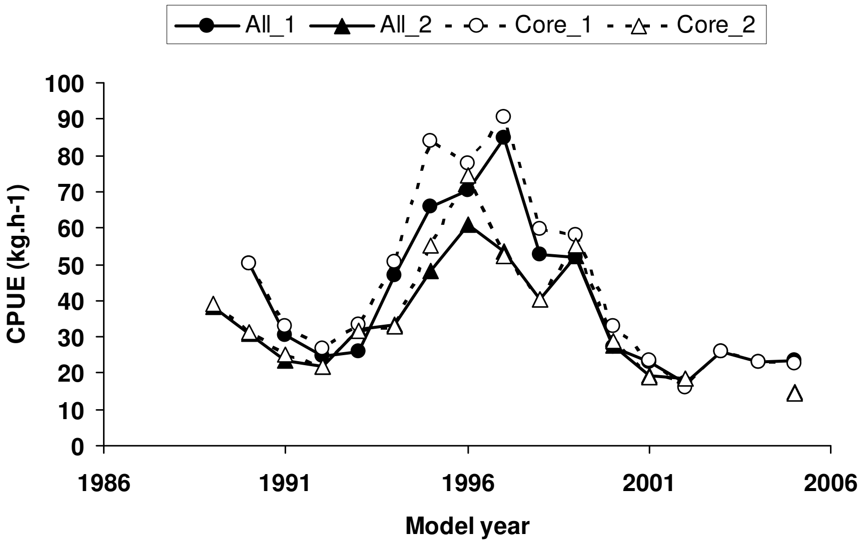

Figure 36: Unstandardised CPUE for the whole of SCI 1 ("All") and the modelled ("Core") area in model time steps 1 and 2.

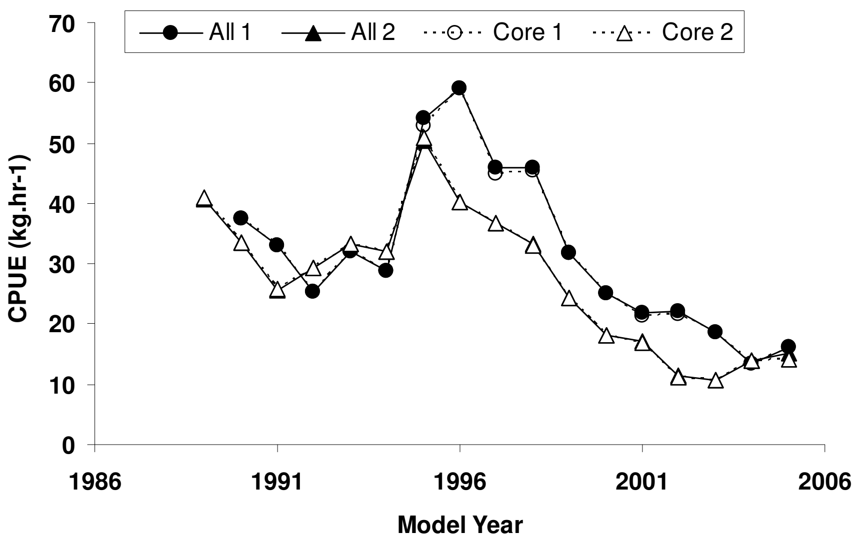

Figure 37: Unstandardised CPUE for the whole of SCI 2 ("All") and the modelled ("Core") area in model time steps 1 and 2.

The appropriateness of incorporating the CPUE series into the assessment model was raised at the SFAWG, since the use of the CPUE as an index of abundance has been questioned because of concerns that changes in these indices may be strongly influenced by changes in catchability caused by the behaviour of scampi rather than by changes in abundance. The sensitivity of the model to inclusion of these data is examined.

2.4.5 Cod-end selectivity of research and commercial trawling

Hartill et al. (2005) estimated the selectivity ogives (using asymmetrical Richards curves) of various cod-end and body meshes in "Florida Flyer" trawl gear in experimental fishing at 400 m depth within the SCI 1 modelled area in 1996. This net design is identical to that used for research trawling and is very similar to nets used throughout the commercial fishery. Research trawling is done using 30 mm cod-end and 80 mm main meshes (throughout the wings, belly, body, and extension piece) and four replicate tows and a total of 1069 measurements were available from the experiment (Figure 38). Various mesh sizes are used in the commercial fishery, but our discussions with fishers (see Hartill et al. 2005) lead us to believe that combining the data from 55 and 65 mm cod-ends allied with 100 mm main meshes would be the closes approximation to an "average" commercial configuration during the modelled period. Thus, eight "replicate" tows and a total of 1948 measurements were available from the experiment. Selection by one or other of the sampling gears is not considered to be a part of the model partition, but proportions selected by each were fitted within the model based on Richards ogives with binomial likelihoods (Bull et al. 2004). Process error (N-based) was set at 20, giving the observations relatively little weight in the model. Cryer at al. (2005) found that the observed selectivity ogives were not fitted well in the model. This may suggest that much of the actual selectivity is taking place elsewhere in the trawl than the cod-end, and that the data do not describe the overall gear selectivity well. The sensitivity to fitting the proportions selected within the model is investigated. Preliminary tree regression analysis of the length frequency data from observer voyages suggests an increase in the median size of scampi landed in 1995 or 1996, which may be indicative of a change (increase) in trawl mesh size. Discussions with fishers suggest that trawl gear has not changed since 1992 or 1993, and although trawl gear details in observer voyage records are limited, they do not provide any evidence that mesh size changed during the mid 1990's. Another possible cause of an increase in median size might be an increase in the use of GPS, improving the accuracy of targeting productive tows, although again, the observer voyage records do not provide evidence of increased use of GPS by the scampi vessels at this time.

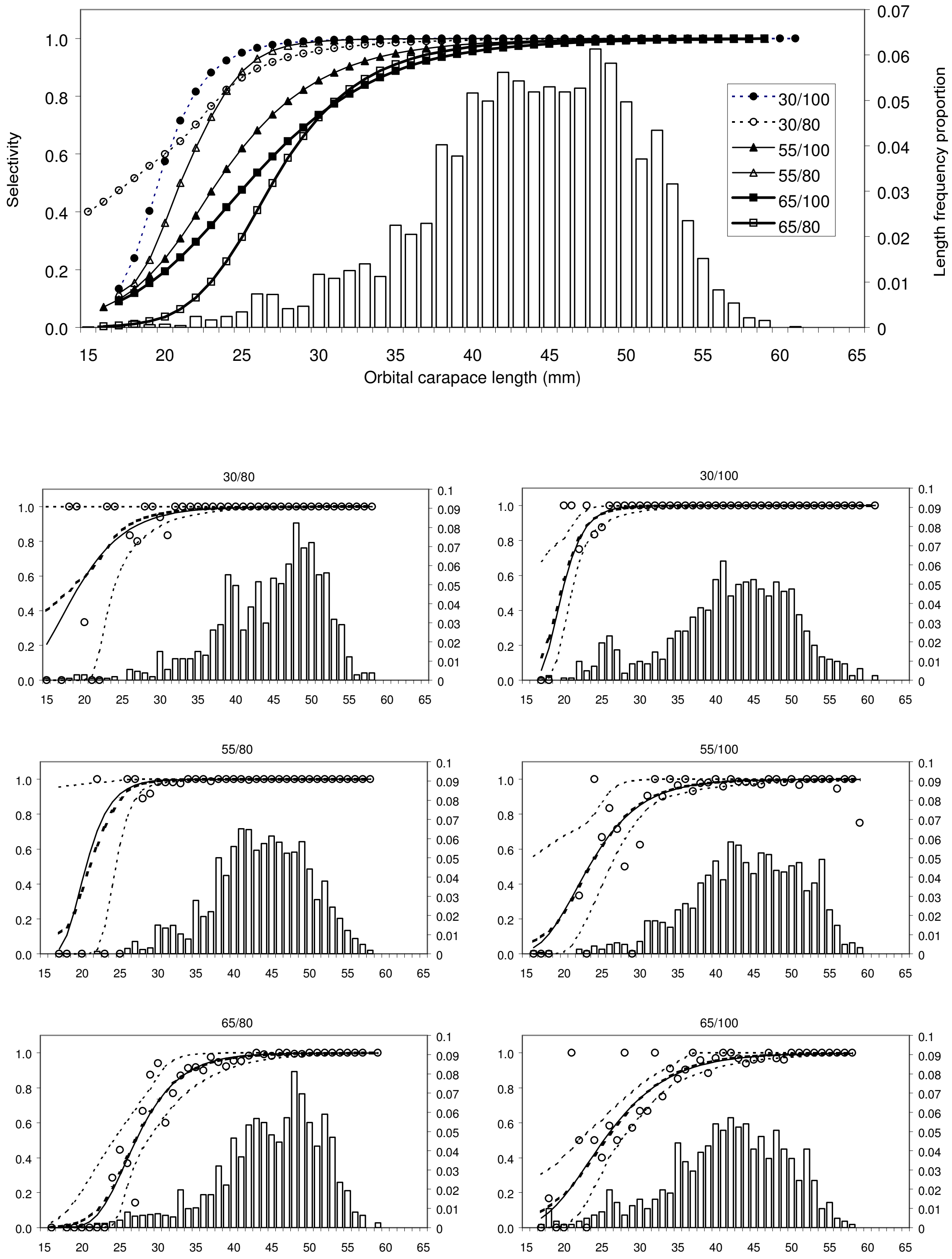

Figure 38: Estimated cod-end selectivity of Florida Flyer trawl gear for scampi (after Hartill et al. 2005). The top panel shows the overall length frequency distribution and estimated cod-end selectivity for six mesh combinations (cod-end/body, millimetres stretched mesh), and the smaller panels show each ogive separately with the observed data points and bootstrap 95% confidence bounds. Histograms show the length frequency distribution of animals used to fit each ogive. The 30/80 data were adopted as representative of research trawl gear and the 55/100 and 65/100 data were combined to represent "average" commercial trawl gear.

2.5 Model estimation and priors

Maximum Probability Density (MPD) fits were found within CASAL using a quasi-Newton optimiser and the BETADIFF automatic differentiation package (see Bull et al. 2004 and references therein). Fitting was done inside the model except for the growth model which was fitted externally and N-based process errors (see Appendix 1). MPD output was analysed using the extract and plot utilities in the CASAL and CASALUTILS libraries running under the general analytical package R (Ihaka & Gentleman 1996, available from http://www.r-project.org).

To reduce the number of fitted parameters, the catchability coefficients (q's) for commercial fishing, research trawling, and photographic surveys were assumed "nuisance" rather than free parameters. The base model was based on that described by Cryer et al. (2005). The only informative priors used in the base model were applied to M and *q-Photo* (Figure 39) and to the YCS vector (to constrain the variability of recruitment). In the base model, process errors were set on the basis of estimation outside the model. Preliminary investigations suggested that the model was sensitive to the N process error specified for the multinomial distributions of proportions at length (trawl survey) and catch at length (commercial fishery) data. The commercial catch at length data were re-examined prior to updating of the model (Section 2.3.6), with some data sets being dropped from the model. Fitting the N process error externally from the model output resulted in almost all weighting being applied to the proportion at length from the trawl survey, with the commercial catch at length data being virtually ignored, and M estimated in these models tended to be markedly higher than expected (about 0.38). The modelling by Cryer et al. (2005), applied roughly equal weighting (N process error) to the proportions at length and catch at length data, and using this approach with the updated data sets resulted in closer to expected estimates of M. The sensitivity of the model to various modelling choices was therefore assessed using sensitivity runs (MPD only) for both N process error approaches wherein informative priors were made uniform (M) or varied (YCS and *q_Photo*), and the cod-end selectivity, commercial CPUE or trawl survey index information was omitted (Table 15). Following examination of the likelihood profiles of the base models, the sensitivity to other assumptions in the model are examined.

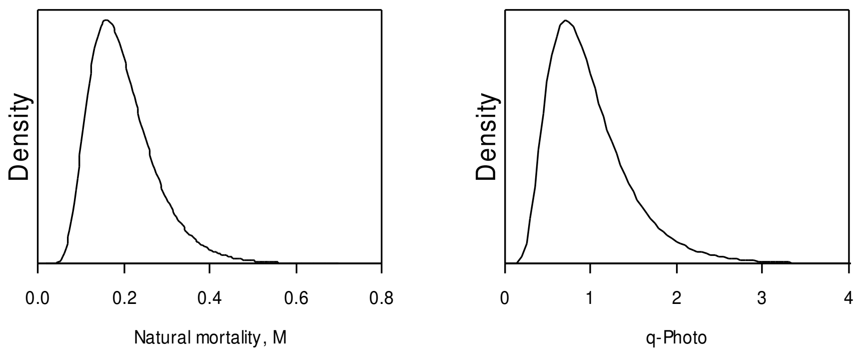

Figure 39: Informative priors in the base model.

Table 15: Summary of sensitivity runs (MPD only)

Model	Description
Base (B)	Base model, photo survey as biomass, informative priors on M and q-Photo, YCS cv = 0.20

Base (B, PE)	Same as base (B), except allowed to fit process error for abundance indices
Base (N)	Base model, photo survey as numbers, informative priors on M and q-Photo, YCS cv = 0.20
Base (N, PE)	Same as base (N), except allowed to fit process error for abundance indices
All_obs	Same as base (N), with all core area observer data included
NoCPUE	Same as base (N) except CPUE data excluded
NoCPUE/TRAWL	Same as base (N) except CPUE & Trawl survey index data excluded
NoCodEnd	Same as base (N) except model not fitted to cod-end selectivity data
q-Photo 1	Same as base (N) except approach 1 prior on q-Photo
q-Photo 2	Same as base (N) except approach 2 prior on q-Photo
FreeM	Same as base (N) except uniform prior on M
cvYCS10%	Same as base (N) except YCS cv = 0.10 (to constrain variation in recruitment)
cvYCS40%	Same as base (N) except YCS cv = 0.40 (to increase variation in recruitment)
YCS smoothing	Same as base (N) except YCS constrained to 3rd order polynomial
YCS smooth & cv10%	Same as base (N) except YCS cv = 0.10 & YCS constrained to 3rd order polynomial
YCS smooth & cv40%	Same as base (N) except YCS cv = 0.40 & YCS constrained to 3rd order polynomial

3 MODEL RESULTS

3.1 SCI 1 - Previous base model structure

3.1.1 N process error fitted externally

The base model MPD fit with the photo survey index used as numbers (Base (N); photo survey as numbers) suggests an unexploited biomass (B_0) of about 5 300 t (Figure 40 and Table 17), and an instantaneous rate of natural mortality (M) of about 0.38 yr^{-1}. Year class strengths were estimated to have been consistently good in the late 1980's, but below-average since 1992, although improving in the most recent years (Figure 40). Spawning stock biomass increased up to the early 1990's, with a consistent decline to about 2000, followed by a slower decline. The 2005 spawning biomass was estimated to be about 70% of the unexploited biomass.

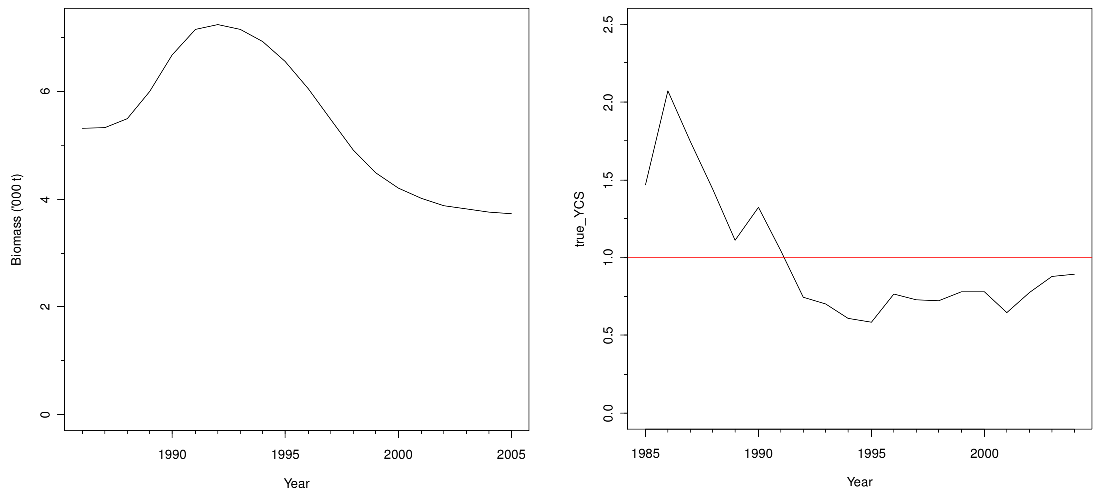

Figure 40: Base case trajectory (N process error fitted externally) of spawning stock biomass and year-class strength for the modelled part of the SCI 1 scampi fishery.

Model fits

None of the models examined fitted all the data well. Fits to the commercial CPUE (Figure 41) and research trawl abundance indices (Figure 42) were poor, with the model unable to recreate the peak observed in each of the indices in the mid 1990's. It has previously been suggested that trawl catchability varied between years for scampi (which is one of the reasons why trawl surveys were superseded by photographic surveys for scampi as an assessment tool). Process error cvs are high for these data sets, and they are largely ignored by the model, although B_0 estimates were sensitive to their exclusion. The fit to the overall trend in the photographic survey index was better, although the observations are quite variable, and the series is short. The fitted process error was consistently low (about 0.1), suggesting that the series is consistent with most of the data in the model. The fits to the commercial trawl fishing selectivity (Figure 43a) and proportion mature (Figure 43d) were very good, but neither had any consequence for the model as the catch at length data were heavily down weighted by the externally fitted N process error, and fitting the maturity ogive does not require compromises to be made in other fits. Research trawl selectivity fits were poor (Figure 43b), with the model preferring far larger values of L_{50} than observed. Cryer et al. (2005) noted that scampi selectivity should be the product of emergence, any pre-selection and cod end selectivity, and therefore might not be expected to fit cod end selectivity particularly well. The fitted selectivity ogive for photographic sampling

(Figure 43c) suggests that burrows of very small (< 10 mm OCL) animals were recorded, which seems unlikely. This may be an artefact of the distribution allowing asymmetry, and the variable quality of the fits to the length distribution data (Figure 45).

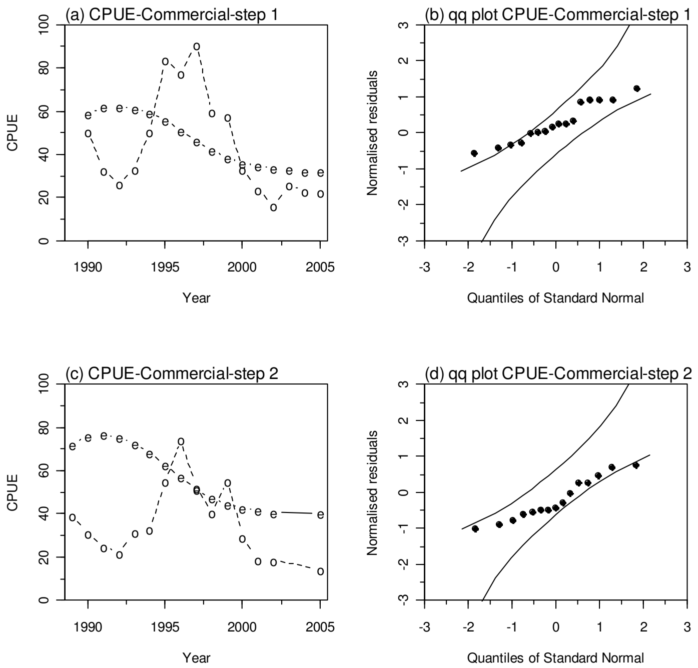

Figure 41: Fits and q-q diagnostic plots to CPUE indices for SCI 1 (o – observed, e – estimated).

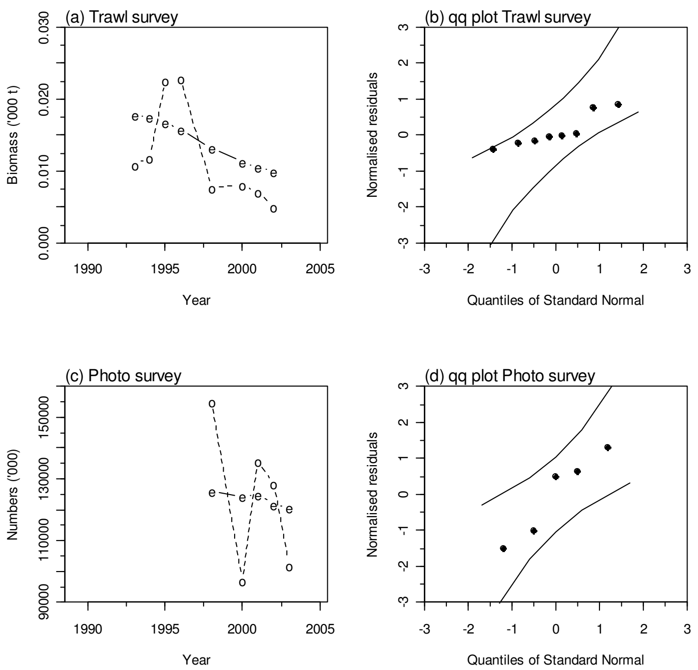

Figure 42: Fits and q-q diagnostic plots to Trawl and Photo survey indices for SCI 1 (o – observed, e – estimated).

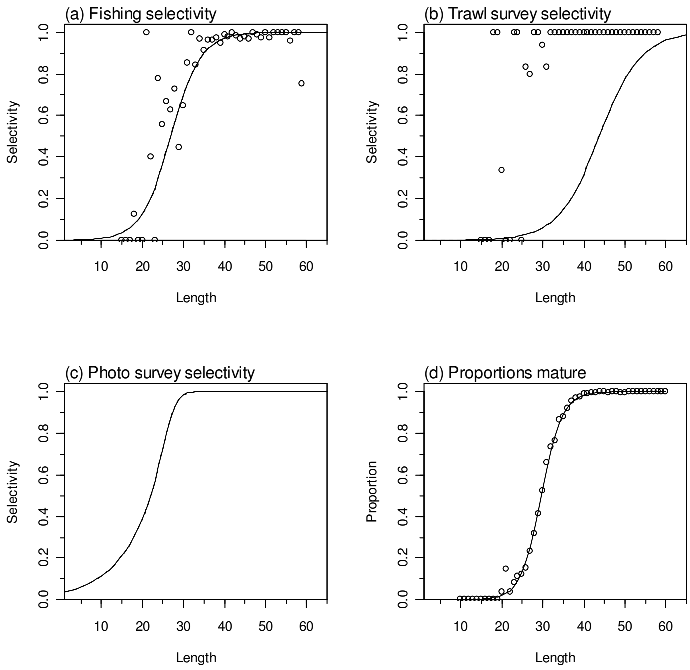

Figure 43: Fitted ogives (lines) and observed data (dots) for selectivity at length for commercial and research trawling, photographic surveys and maturity at length for SCI 1.

The fit to the length frequency distributions derived from photographic surveys was variable (Figure 45), but may be as good as could be expected given the uncertainties in their derivation. The general form of the fits to the research trawl length frequency data were reasonable (Figure 46 to Figure 48), but the variability observed between years was not matched by the model, and neither was the observed variation in sex ratio (Figure 44). This may partly reflect the variability in timing of the sampling within time steps. As might be expected, the fits to the heavily down weighted commercial length frequency data were poor (Figure 49 & Figure 50).

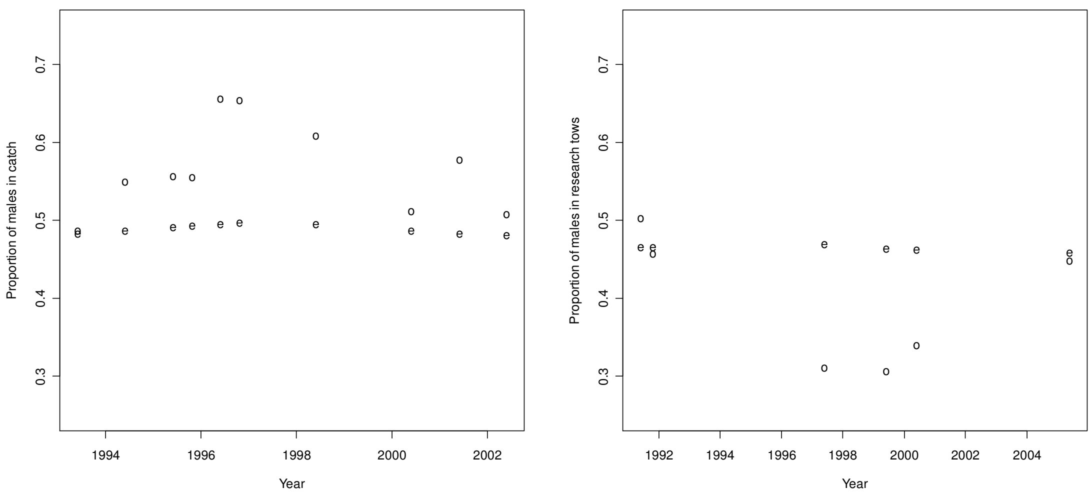

Figure 44: Observed (o) and modelled (e) proportion of males in research trawl (left) and commercial catch data (as estimated by observers, right) for SCI 1.

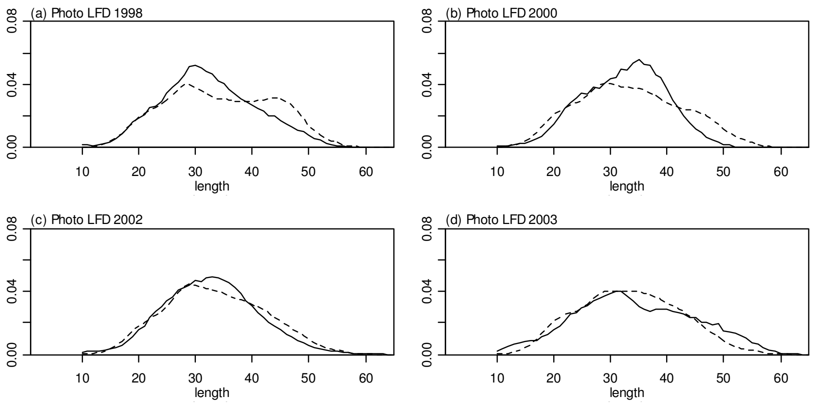

Figure 45: Observed (solid lines) and fitted (dashed lines) length frequency distributions from photographic surveys for SCI 1.

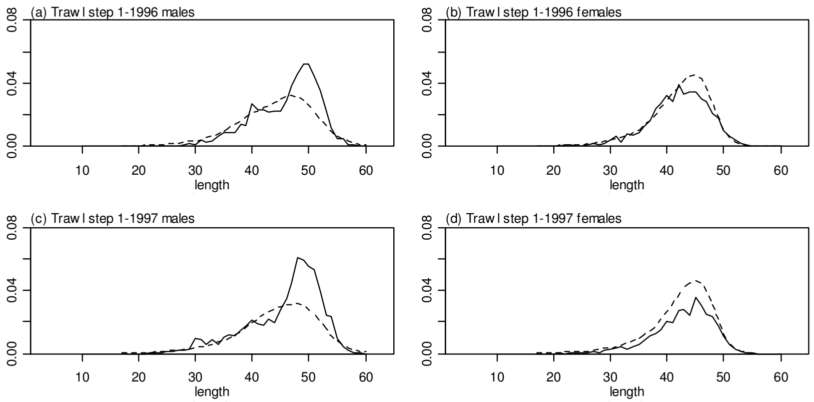

Figure 46: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 trawl surveys for SCI 1.

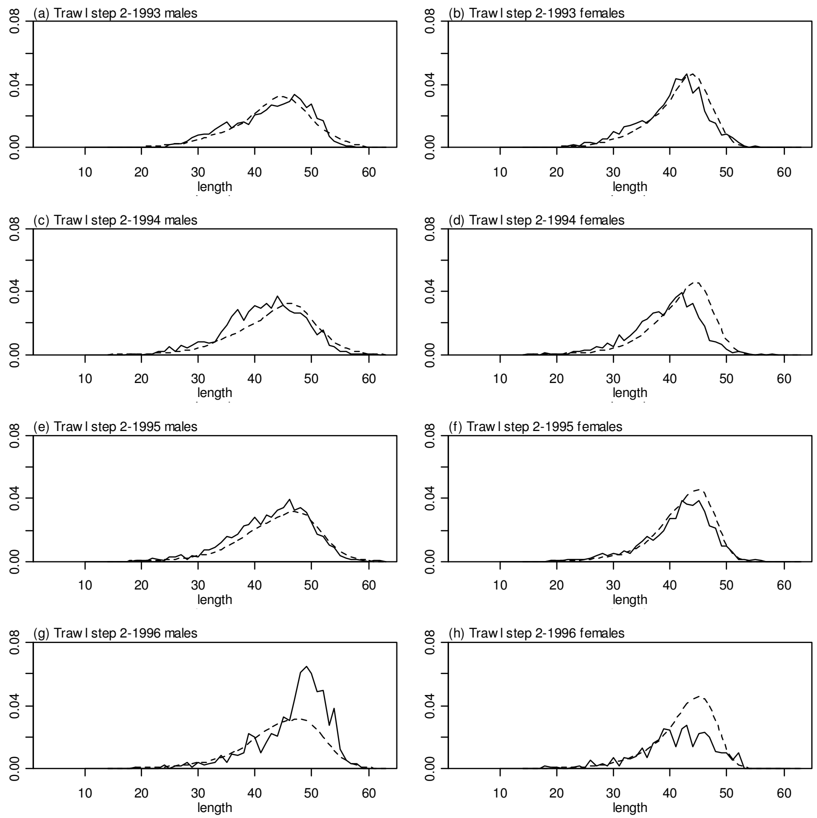

Figure 47: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys (1993-1996) for SCI 1.

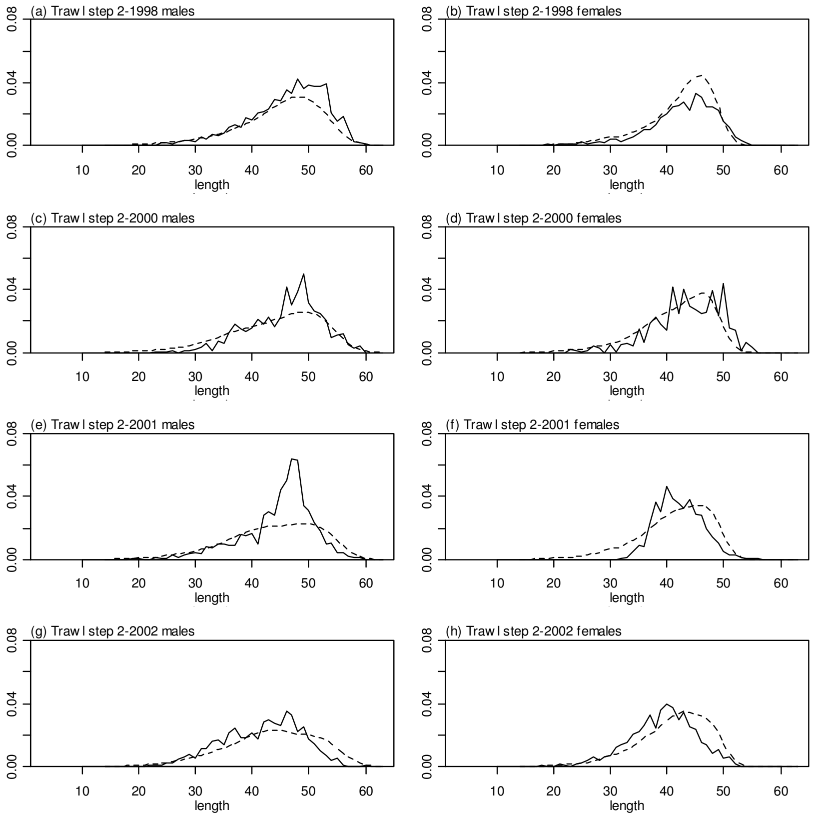

Figure 48: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys (1998-2002) for SCI 1.

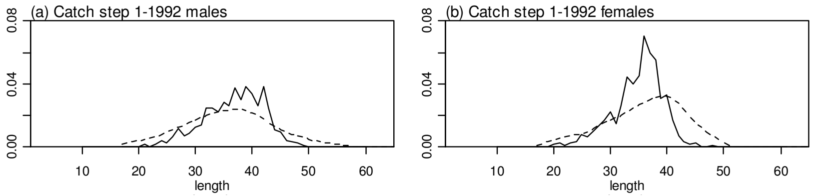

Figure 49: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 commercial catch for SCI 1.

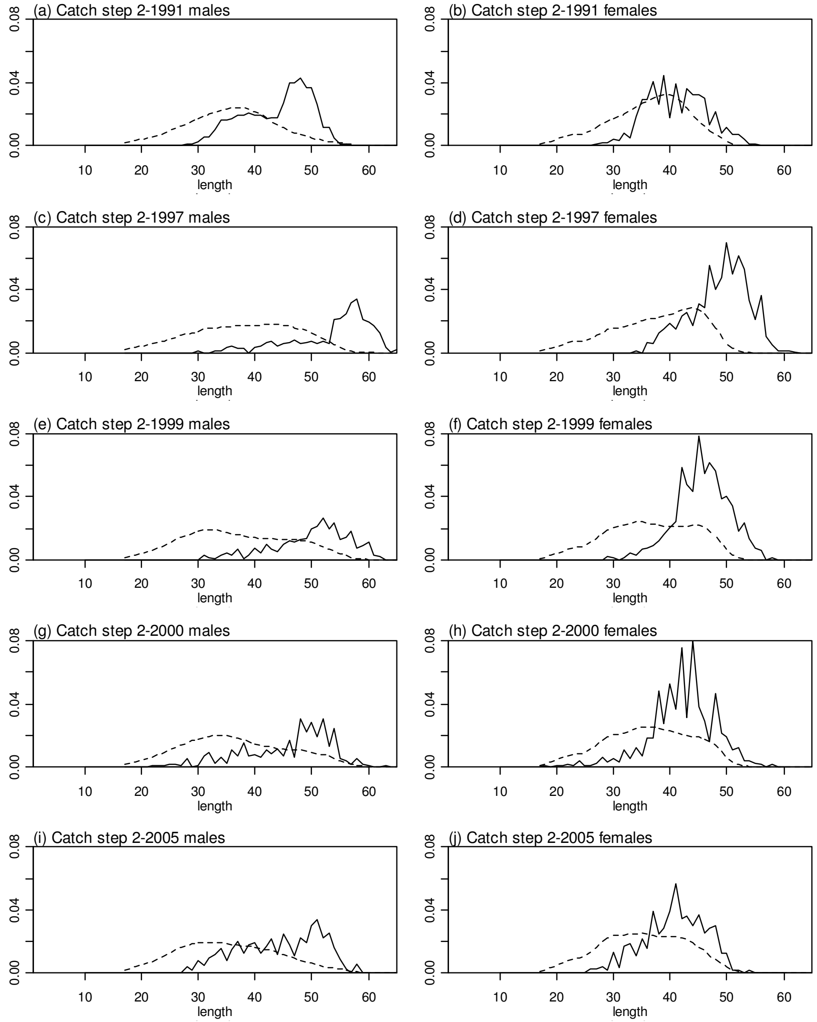

Figure 50: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 commercial catch for SCI 1.

Likelihood profiling of the base model (by fixing key parameters at a range of values and refitting the model at each level) suggested that a wide range of biomass levels produced similar likelihoods (the overall profile was relatively flat, Figure 51), but only a narrow range of M was tolerated (the overall profile was relatively steep, Figure 52). Note the scales are different in the plots. Additions to the likelihood components for each term are provided in Table 16. The likelihood profile for B_0 did not respond strongly to any of the relative abundance data sets (CPUE, photo or trawl survey), and the proportion (and catch) at length and selectivity data provided inconsistent signals. The trawl proportion at length data (particularly the step 2 [January to September] series) strongly suggested a very low biomass (about 1 000 t), while the research trawl selectivity data indicated a far larger B_0. The likelihood profile for B_0 did not respond to the (down-weighted) commercial catch at length data, but the commercial trawl selectivity data did indicate the B_0 should be at > 2 000 t. The priors for recruitment YCS and q-Photo were both influential, with the YCS constraint suggesting a B_0 > 3 000 to 4 000 t, and q-Photo suggesting a value between 3 000 to 7 000 t.

The likelihood profile for M was very strongly affected by the research proportion at length and both research and commercial trawl selectivity data sets (though in conflicting directions) and to a far lesser extent by the prior for recruitment YCS, and the photo survey relative abundance index. Both trawl survey proportion at length data series suggested high M values (> 0.4), while the commercial trawl selectivity suggested an M > 0.25 and the research trawl selectivity an M < 0.15. The prior on recruitment YCS suggested an M > 0.3, while the photo survey index suggested an M > 0.175.

The base (N) model produced slightly higher estimates of B_0 and B_{2005} than the base (B) model (photo survey as biomass), although the trends over time and 2005 biomass as a proportion of B_0 were almost identical. The base (N) model was not sensitive to the inclusion of all the observer data, relaxing the prior on M, the flexibility to fit process error relative to the abundance indices, or the constraint on YCS to fit a 3rd order polynomial (Table 17). However, it was sensitive to applying a different prior on q-Photo, excluding the CPUE and trawl survey indices, and the amount of constraint put on the recruitment variability. The model excluding the cod end selectivity data and the two models with YCS cv constrained to 0.1 failed to converge (minimiser convergence threshold set to 0.002). Applying the prior for q-Photo based on approach 1 (uniform distributions of occupancy and detection, resulting in a prior with high cv) resulted in an estimate of q-Photo of 0.06 (compared to 0.58 in the base model), with an associated dramatic increase in the estimate of B_0. Applying the prior for q-Photo based on approach 2 produced similar output to the base model. Relaxing the constraint put on recruitment variability (increasing YCS cv to 0.4) decreased the estimate of B_0.

With the exception of the run using the prior for q-Photo based on approach 1 (and resulting in a very low q-Photo and a B_0 estimate of almost 46 000 t), none of the estimates of B_0 from the converged sensitivity fits seem implausible, ranging from 3 034 to 5 619 t. M appeared relatively insensitive to the modelling choices (consistently about 0.38 in converged fits), which may be an artefact of the imposed growth model and observed length frequency distributions (Cryer at al. 2005), but is higher than anticipated. Of the fits that converged, other than the run with very low q-Photo and the least constrained YCS sensitivity runs, B_{2005} was consistently estimated to be 67 - 71% of B_0.

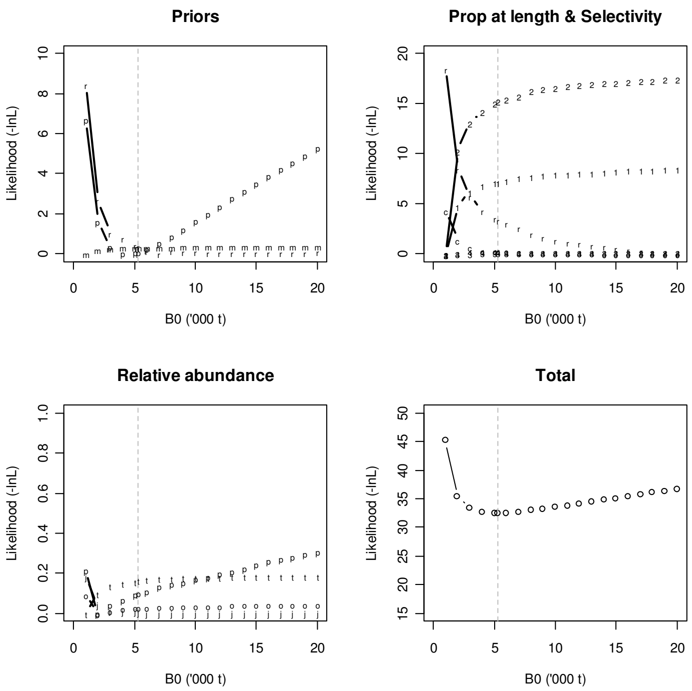

Figure 51: Likelihood profiles for the base model (N process error fitted externally) when B_0 is fixed in the model for SCI 1. Figures show profiles for main priors (top left: p – qPhoto, r – recruitment YCS, m – natural mortality), proportion at length data (top right: 1 – trawl survey step 1, 2 – trawl survey step 2, 3 – comm observer step 1, 4 – comm observer step 2, c – selectivity of commercial trawl, r – selectivity of research trawl), relative abundance data (bottom left: j – CPUE step 1, o – CPUE step 2, p – photo survey, t – trawl survey) individually, and for the whole model (bottom right).

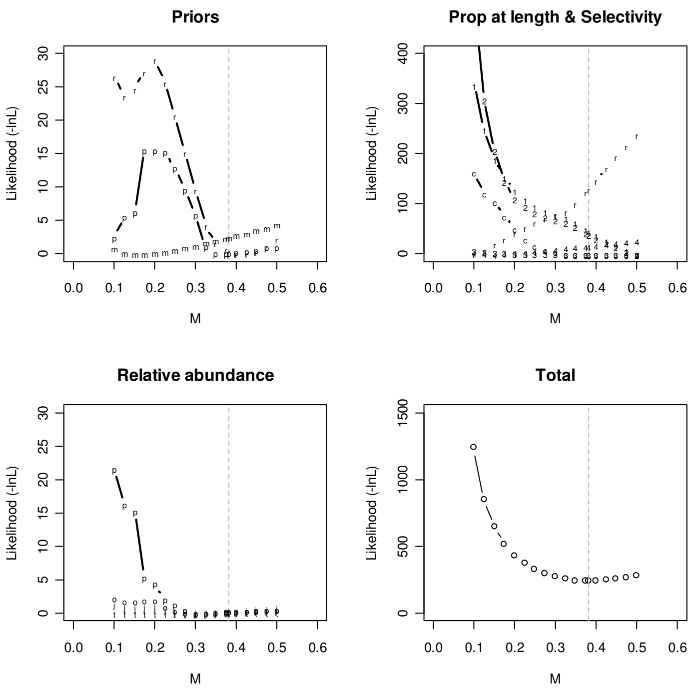

Figure 52: Likelihood profiles for the base model (N process error fitted externally) when M is fixed in the model for SCI 1. Figures show profiles for main priors (top left: p – qPhoto, r – recruitment YCS, m – natural mortality), proportion at length data (top right: 1 – trawl survey step 1, 2 – trawl survey step 2, 3 – comm observer step 1, 4 – comm observer step 2, c – selectivity of commercial trawl, r – selectivity of research trawl), relative abundance data (bottom left: j – CPUE step 1, o – CPUE step 2, p – photo survey, t – trawl survey) individually, and for the whole model (bottom right).

Table 16: Additions to likelihood components (over and above the minimum for each) for the base model (Base (N)) for each data set and for the priors and penalties when B_0 or M are fixed at values between 1 000 and 20 000 t and 0.1 and 0.5, respectively for SCI 1. The MPD fit for the base model is in bold font.

	relative abundance				proportion at length								prior											penalty		
B_0	CPUE-Commercial-Jan	CPUE-Commercial-Oct	PhotoSurvey	TrawlSurvey	PhotoProportionAtLength-Jan	TrawlSurveyProportionAtLength-Jan	TrawlSurveyProportionAtLength-Oct	CommercialCatchLengthJan	CommercialCatchLengthOct	Cryer_Oliver_maturity	SHSP05_expt_comm	SHSP05_expt_rsch	prior_on_initialization.B0	prior_on_natural_mortality.all	prior_on_relative_abundance[PhotoSurvey].cv_process_error	prior_on_recruitment.YCS	prior_on_maturity_props.all	prior_on_selectivity[FishingSel].male	prior_on_selectivity[TrawlSurveySel].male	prior_on_selectivity[PhotoSurveySel].male	prior_on_q_CPUE-Commercialq	prior_on_q_PhotoSurveyq	prior_on_q_TrawlSurveyq	OctCatchMustBeTaken	JanCatchMustBeTaken	YCS_average_1
1.000	0.2	0.1	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	4.2	18.5	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0	3.3	6.7	3.4	0.0	0.0	0.0
2.000	0.0	0.0	0.0	0.1	0.0	10.3	4.8	0.1	0.1	0.0	1.4	8.4	0.7	0.2	0.0	2.7	0.0	0.0	0.0	0.0	2.4	1.6	2.5	0.0	0.0	0.0
3.000	0.0	0.0	0.0	0.1	0.2	13.1	6.3	0.2	0.1	0.0	0.7	5.8	1.1	0.3	0.0	1.0	0.0	0.0	0.0	0.0	2.0	0.3	2.0	0.0	0.0	0.0
4.000	0.0	0.0	0.1	0.2	0.4	14.3	6.8	0.3	0.1	0.0	0.3	4.3	1.4	0.3	0.0	0.8	0.0	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0
5.000	0.0	0.0	0.1	0.2	0.5	15.0	7.1	0.3	0.1	0.0	0.3	3.6	1.6	0.3	0.0	0.4	0.0	0.0	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0
5.304	**0.0**	**0.0**	**0.1**	**0.2**	**0.5**	**15.3**	**7.2**	**0.3**	**0.1**	**0.0**	**0.3**	**3.4**	**1.7**	**0.3**	**0.0**	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**1.4**	**0.1**	**1.4**	**0.0**	**0.0**	**0.0**
6.000	0.0	0.0	0.1	0.2	0.6	15.6	7.4	0.2	0.1	0.0	0.3	3.1	1.8	0.3	0.0	0.2	0.0	0.0	0.0	0.0	1.2	0.2	1.3	0.0	0.0	0.0
7.000	0.0	0.0	0.1	0.2	0.6	15.9	7.7	0.2	0.1	0.0	0.3	2.6	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.5	1.1	0.0	0.0	0.0
8.000	0.0	0.0	0.1	0.2	0.7	16.3	7.8	0.2	0.1	0.0	0.2	2.0	2.1	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.9	0.9	0.9	0.0	0.0	0.0
9.000	0.0	0.0	0.2	0.2	0.7	16.5	7.9	0.2	0.1	0.0	0.1	1.7	2.2	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.8	1.2	0.8	0.0	0.0	0.0
10.000	0.0	0.0	0.2	0.2	0.8	16.7	8.0	0.2	0.1	0.0	0.1	1.4	2.3	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.7	1.6	0.7	0.0	0.0	0.0
11.000	0.0	0.0	0.2	0.2	0.8	16.9	8.0	0.2	0.1	0.0	0.1	1.2	2.4	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.6	2.0	0.6	0.0	0.0	0.0
12.000	0.0	0.0	0.2	0.2	0.8	17.0	8.1	0.2	0.2	0.0	0.1	1.0	2.5	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.5	2.4	0.5	0.0	0.0	0.0
13.000	0.0	0.0	0.2	0.2	0.9	17.1	8.1	0.2	0.2	0.0	0.1	0.9	2.6	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.4	2.8	0.4	0.0	0.0	0.0
14.000	0.0	0.0	0.2	0.2	0.9	17.2	8.2	0.2	0.2	0.0	0.1	0.7	2.6	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.4	3.1	0.4	0.0	0.0	0.0
15.000	0.0	0.0	0.2	0.2	0.9	17.2	8.3	0.2	0.2	0.0	0.0	0.5	2.7	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.3	3.5	0.3	0.0	0.0	0.0
16.000	0.0	0.0	0.3	0.2	1.0	17.3	8.4	0.2	0.2	0.0	0.0	0.4	2.8	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.2	3.9	0.2	0.0	0.0	0.0
17.000	0.0	0.0	0.3	0.2	1.0	17.4	8.4	0.2	0.2	0.0	0.0	0.3	2.8	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.2	4.2	0.2	0.0	0.0	0.0
18.000	0.0	0.0	0.3	0.2	1.0	17.4	8.4	0.2	0.2	0.0	0.0	0.2	2.9	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.1	4.6	0.1	0.0	0.0	0.0
19.000	0.0	0.0	0.3	0.2	1.0	17.5	8.5	0.2	0.2	0.0	0.0	0.1	2.9	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.1	4.9	0.1	0.0	0.0	0.0
20.000	0.0	0.0	0.3	0.2	1.0	17.5	8.5	0.2	0.2	0.0	0.0	0.0	3.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0
M																										
0.100	1.2	2.2	21.6	0.0	147.0	512.0	338.2	2.8	8.0	0.0	162.9	0.0	0.2	0.7	0.0	26.6	0.0	0.0	0.0	0.0	3.5	2.4	2.0	6.8	0.2	0.3
0.125	0.9	1.9	16.2	0.0	100.5	308.8	249.0	0.8	5.2	0.0	120.6	6.6	0.1	0.2	0.0	23.7	0.0	0.0	0.0	0.0	3.5	5.6	2.0	3.2	0.0	0.2
0.150	0.8	1.8	15.1	0.0	67.8	206.9	189.9	0.0	4.0	0.0	105.3	18.9	0.1	0.0	0.0	24.8	0.0	0.0	0.0	0.0	3.5	6.2	2.0	1.1	0.0	0.3
0.175	1.0	2.1	5.3	0.0	49.8	145.6	152.8	1.2	2.7	0.0	76.1	30.0	0.0	0.0	0.0	27.3	0.0	0.0	0.0	0.0	3.4	15.6	2.1	0.2	0.0	0.3
0.200	1.0	2.0	4.3	0.0	37.1	110.5	126.9	2.8	1.8	0.0	50.9	42.3	0.0	0.2	0.0	29.1	0.0	0.0	0.0	0.0	3.3	15.6	2.1	0.0	0.0	0.3
0.225	0.5	1.1	2.1	0.0	26.9	94.3	108.5	4.2	1.2	0.0	30.5	53.3	0.0	0.4	0.0	25.7	0.0	0.0	0.0	0.0	3.0	15.2	2.0	0.0	0.0	0.3
0.250	0.3	0.5	1.2	0.0	19.8	82.0	94.3	5.9	0.7	0.0	17.6	63.3	0.1	0.7	0.0	20.7	0.0	0.0	0.0	0.0	2.8	12.8	1.9	0.0	0.0	0.2
0.275	0.1	0.1	0.4	0.0	15.3	73.5	84.2	7.7	0.4	0.0	9.1	71.2	0.3	1.0	0.0	15.2	0.0	0.0	0.0	0.0	2.5	9.6	1.7	0.0	0.0	0.1
0.300	0.0	0.0	0.0	0.1	12.5	67.2	76.5	9.4	0.3	0.0	4.0	78.7	0.5	1.3	0.0	9.6	0.0	0.0	0.0	0.0	2.0	5.8	1.4	0.0	0.0	0.1
0.325	0.0	0.0	0.0	0.2	11.4	64.3	71.8	11.1	0.2	0.0	0.7	83.8	1.2	1.7	0.0	4.2	0.0	0.0	0.0	0.0	1.2	1.1	0.6	0.0	0.0	0.0
0.350	0.1	0.1	0.1	0.2	7.5	54.5	62.5	13.0	0.2	0.0	0.0	99.4	1.9	2.0	0.0	1.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
0.375	0.1	0.2	0.2	0.2	3.6	42.3	49.7	15.1	0.1	0.0	0.0	122.6	2.0	2.4	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.1	0.1	0.0	0.0	0.0
0.383	**0.2**	**0.2**	**0.2**	**0.2**	**2.7**	**38.9**	**45.8**	**15.8**	**0.1**	**0.0**	**0.0**	**130.0**	**2.0**	**2.5**	**0.0**	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.3**	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**
0.400	0.2	0.3	0.3	0.2	1.2	31.4	37.4	17.3	0.1	0.0	0.1	146.6	2.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.2	0.0	0.0	0.0
0.425	0.3	0.3	0.3	0.2	0.1	21.7	26.4	19.4	0.0	0.0	0.1	170.5	2.1	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.0	0.0	0.0
0.450	0.4	0.4	0.4	0.2	0.0	13.5	16.4	21.5	0.0	0.0	0.2	193.6	2.2	3.6	0.0	0.4	0.0	0.0	0.0	0.0	0.1	0.6	0.4	0.0	0.0	0.0
0.475	0.5	0.5	0.4	0.1	0.7	6.4	7.8	23.6	0.0	0.0	0.3	216.1	2.3	4.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.9	0.4	0.0	0.0	0.0
0.500	0.7	0.6	0.4	0.1	2.2	0.0	0.0	25.8	0.0	0.0	0.4	239.1	2.3	4.4	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.9	0.6	0.0	0.0	0.0

Table 17: Estimated parameters and quantities from the base case and sensitivity MPD fits for the SCI 1 modelled area (N process error on proportion at length and catch at length fitted externally). Fits in italics (NoCodEnd, cvYCS10% and YCS smoothing & cv10%) did not converge.

Estimated parameters	Base (B)	Base (B, PE)	Base (N)	Base (N, PE)	All_obs	NoCPUE	NoCPUE/TRAWL	*NoCodEnd*	q-Photo 1	q-Photo 2	FreeM	*cvYCS10%*	cvYCS40%	YCS smoothing	*YCS smooth & cv10%*	YCS smooth & cv40%
initialization.B0	4912	4695	5304	5022	5074	4281	3513	*1105*	45865	5619	5204	*2672*	4311	5432	*3034*	3978
natural_mortality.all	0.383	0.382	0.383	0.381	0.376	0.382	0.382	*0.524*	0.387	0.383	0.385	*0.465*	0.383	0.385	*0.484*	0.384
PhotoSurvey.cv_process_error	0.125	0.127	0.096	0.095	0.096	0.096	0.095	*0.094*	0.099	0.097	0.097	*0.114*	0.084	0.105	*0.122*	0.094
CPUE-Commercialq	0.0090	0.0079	0.0083	0.0074	0.0088			*0.0680*	0.0009	0.0078	0.0084	*0.0165*	0.0104	0.0081	*0.0149*	0.0113
PhotoSurveyq	0.5595	0.5875	0.5802	0.6161	0.6173	0.7246	0.8898	*2.8594*	0.0636	0.5457	0.5895	*0.8769*	0.8547	0.5726	*0.7657*	0.9349
TrawlSurveyq	0.0046	0.0041	0.0042	0.0037	0.0042	0.0053		*0.0897*	0.0005	0.0040	0.0044	*0.0150*	0.0046	0.0042	*0.0142*	0.0050
R0	1.22E+08	1.16E+08	1.31E+08	1.23E+08	1.21E+08	1.06E+08	8.68E+07	*6.06E+07*	1.17E+09	1.39E+08	1.31E+08	*1.07E+08*	1.07E+08	1.36E+08	*1.35E+08*	9.94E+07
YCS_1985	1.48	1.48	1.49	1.49	1.50	1.49	1.47	*1.05*	1.49	1.49	1.49	*1.00*	2.65	1.93	*0.99*	2.70
YCS_1986	2.07	2.07	2.10	2.10	2.19	2.13	2.15	*1.52*	2.07	2.10	2.09	*1.19*	2.24	1.78	*1.26*	2.10
YCS_1987	1.78	1.79	1.77	1.78	1.74	1.77	1.76	*1.92*	1.73	1.77	1.77	*1.52*	1.60	1.62	*1.39*	1.72
YCS_1988	1.45	1.45	1.46	1.46	1.46	1.47	1.48	*1.63*	1.44	1.46	1.46	*1.50*	1.75	1.47	*1.41*	1.48
YCS_1989	1.11	1.12	1.11	1.12	1.11	1.11	1.11	*1.16*	1.10	1.11	1.11	*1.21*	0.99	1.33	*1.34*	1.31
YCS_1990	1.31	1.32	1.32	1.33	1.31	1.32	1.32	*1.41*	1.31	1.32	1.32	*1.30*	1.34	1.17	*1.22*	1.14
YCS_1991	1.03	1.04	1.04	1.04	1.03	1.03	1.04	*1.12*	1.03	1.04	1.04	*1.08*	0.97	0.99	*1.05*	0.94
YCS_1992	0.74	0.74	0.74	0.74	0.73	0.74	0.74	*0.84*	0.74	0.74	0.74	*0.84*	0.66	0.80	*0.87*	0.73
YCS_1993	0.69	0.70	0.70	0.70	0.69	0.70	0.70	*0.73*	0.70	0.70	0.70	*0.74*	0.62	0.66	*0.74*	0.58
YCS_1994	0.61	0.61	0.61	0.61	0.61	0.61	0.61	*0.67*	0.61	0.61	0.61	*0.71*	0.52	0.60	*0.71*	0.51
YCS_1995	0.58	0.58	0.58	0.59	0.58	0.58	0.58	*0.65*	0.59	0.58	0.58	*0.79*	0.45	0.62	*0.76*	0.51
YCS_1996	0.76	0.76	0.77	0.77	0.77	0.77	0.77	*0.79*	0.78	0.77	0.77	*0.86*	0.66	0.68	*0.84*	0.56
YCS_1997	0.73	0.73	0.74	0.73	0.73	0.74	0.73	*0.75*	0.74	0.74	0.74	*0.93*	0.57	0.74	*0.90*	0.59
YCS_1998	0.75	0.74	0.74	0.73	0.73	0.74	0.74	*0.71*	0.75	0.74	0.74	*0.89*	0.56	0.77	*0.92*	0.60
YCS_1999	0.81	0.81	0.81	0.80	0.80	0.80	0.80	*0.75*	0.82	0.81	0.80	*0.92*	0.61	0.77	*0.91*	0.59
YCS_2000	0.81	0.80	0.81	0.80	0.81	0.81	0.80	*0.79*	0.83	0.81	0.81	*0.91*	0.62	0.76	*0.89*	0.56
YCS_2001	0.69	0.68	0.68	0.67	0.68	0.67	0.67	*0.65*	0.68	0.68	0.68	*0.87*	0.45	0.75	*0.90*	0.53
YCS_2002	0.84	0.83	0.81	0.80	0.81	0.81	0.81	*0.79*	0.82	0.81	0.81	*0.94*	0.58	0.77	*0.93*	0.55
YCS_2003	0.91	0.90	0.91	0.90	0.91	0.91	0.91	*0.95*	0.90	0.91	0.91	*0.99*	0.73	0.84	*0.98*	0.64
YCS_2004	0.92	0.92	0.92	0.92	0.93	0.92	0.93	*0.95*	0.92	0.92	0.93	*0.97*	0.77	0.97	*1.01*	0.84
Maturity50	30.18	30.18	30.18	30.18	30.18	30.18	30.18	*30.20*	30.18	30.18	30.18	*30.18*	30.18	30.18	*30.15*	30.18
MaturityTo95	7.34	7.34	7.34	7.34	7.34	7.34	7.34	*7.29*	7.35	7.34	7.34	*7.36*	7.34	7.34	*7.36*	7.34
Comm50	27.51	27.62	27.47	27.61	28.22	27.53	27.70	*37.10*	27.12	27.45	27.52	*28.72*	27.47	27.47	*29.70*	27.55
CommTo95	10.64	10.70	10.71	10.72	10.42	10.69	10.40	*3.96*	11.07	10.73	10.68	*6.52*	10.95	10.71	*7.61*	10.77
CommAsy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*2.06*	1.00	1.00	1.00	*1.52*	1.00	1.00	*1.74*	1.00
Rsch50	44.40	44.35	44.30	44.28	43.77	44.37	44.53	*51.07*	44.20	44.29	44.49	*47.77*	42.66	44.30	*48.00*	42.78
RschTo95	14.75	14.75	14.75	14.76	14.66	14.75	14.76	*5.71*	14.71	14.75	14.77	*5.05*	14.67	14.71	*5.10*	14.68
RschAsy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*3.16*	1.00	1.00	1.00	*5.31*	1.00	1.00	*4.80*	1.00
Photo50	22.58	22.48	22.45	22.37	22.26	22.49	22.51	*29.45*	22.34	22.44	22.57	*24.85*	21.54	22.69	*25.68*	21.89
PhotoTo95	6.51	6.45	6.47	6.52	6.48	6.47	6.60	*13.76*	6.60	6.49	6.52	*8.09*	6.52	6.27	*8.43*	6.19
PhotoAsy	7.08	7.21	7.10	7.20	7.14	7.10	7.17	*2.02*	6.71	7.08	7.01	*2.81*	7.31	7.28	*2.62*	7.76
B2005	3453	3269	3723	3495	3538	2941	2355	*636*	34820	3966	3647	*2118*	2346	3791	*2469*	2143
B2005/B1985	0.70	0.70	0.70	0.70	0.70	0.69	0.67	*0.58*	0.76	0.71	0.70	*0.79*	0.54	0.70	*0.81*	0.54

3.1.2 N process error equal

As discussed earlier, given the apparent sensitivity of the model to the relative weighting of the proportion at length and catch at length data, it was considered useful to also examine the sensitivity of the model with equal weight given to the length distribution data sets.

The base model MPD fit suggests a similar stock trajectory to the model with externally fitted N process error (SSB increased up to the early 1990's, with a consistent decline to about 2000, followed more stable period), but with a higher unexploited biomass (B_0) of about 7 100 t (Table 19 and Figure 53), and a lower (but probably more realistic) instantaneous rate of natural mortality (M) of about 0.24 yr^{-1}. Year class strengths also showed a similar pattern, and were estimated to have been consistently good in the late 1980's, but below-average since 1992, although improving in the most recent years (Figure 53). The 2005 spawning biomass was estimated to be about 83% of the unexploited biomass.

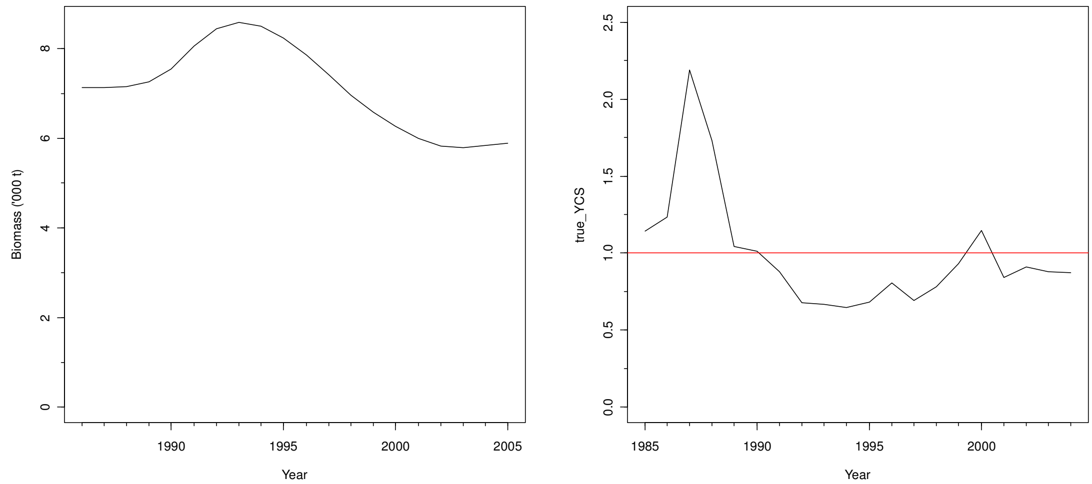

Figure 53: Base case trajectory (N process error equal) of spawning stock biomass and year-class strength for the modelled part of the SCI 1 scampi fishery.

Model fits

Applying equal N process error to the research trawl and commercial length data altered their relative weighting within the model compared to the model with externally fitted values (altering the resulting outputs), but did not appear to have a large effect on the overall quality of fits (although the objective function value was lower [better] for the model with externally fitted values).

The main differences in the fits between the two N process error approaches were that with the equal weighting on the commercial data, both selectivity ogives estimated L_{50} values greater than observed (Figure 56), and while the fits to the commercial length data (Figure 62 & Figure 63) are generally improved, the fits to the length data for both the photographic survey (Figure 58) and research trawl survey (Figure 59 to Figure 61) are slightly worse. The fit to the observed sex ratio in the research and observer data was slightly worse than the earlier model (measured as average absolute difference in proportion males between observed and estimated data).

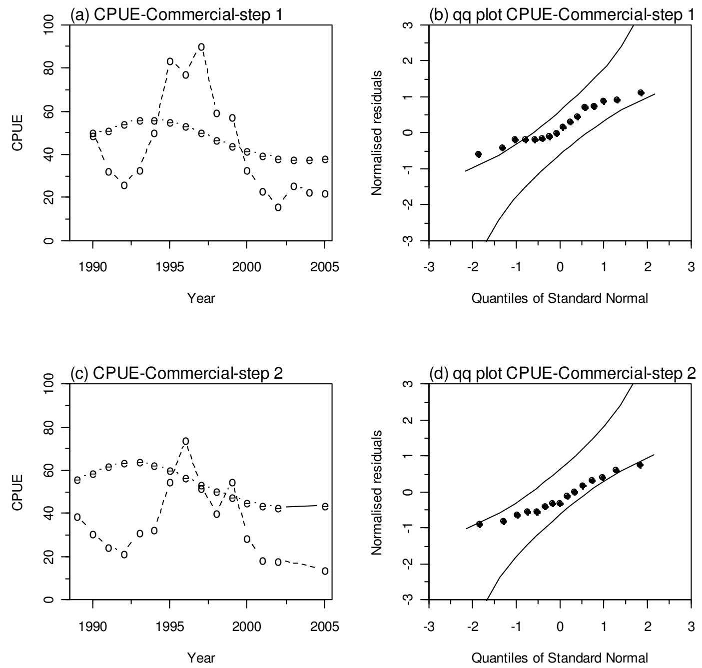

Figure 54: Fits and q-q diagnostic plots to CPUE indices (o – observed, e – estimated) for SCI 1.

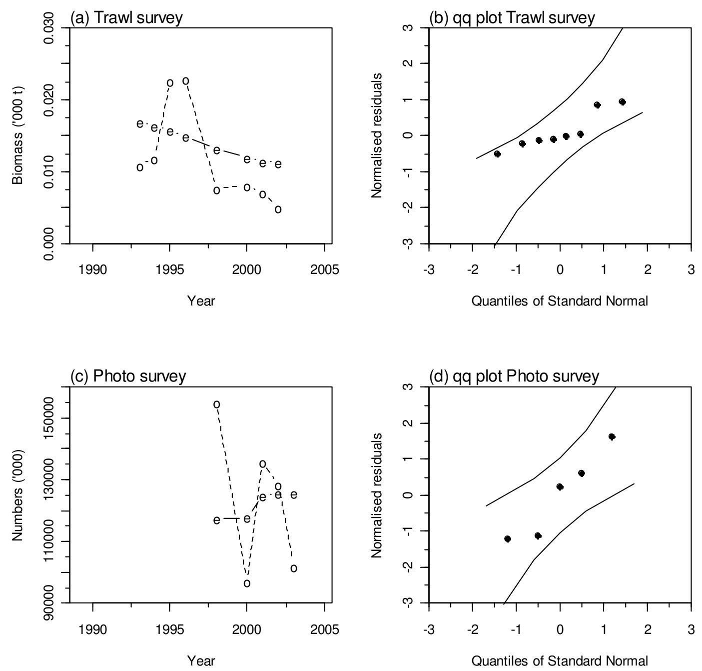

Figure 55: Fits and q-q diagnostic plots to Trawl and Photo survey indices (o – observed, e – estimated) for SCI 1.

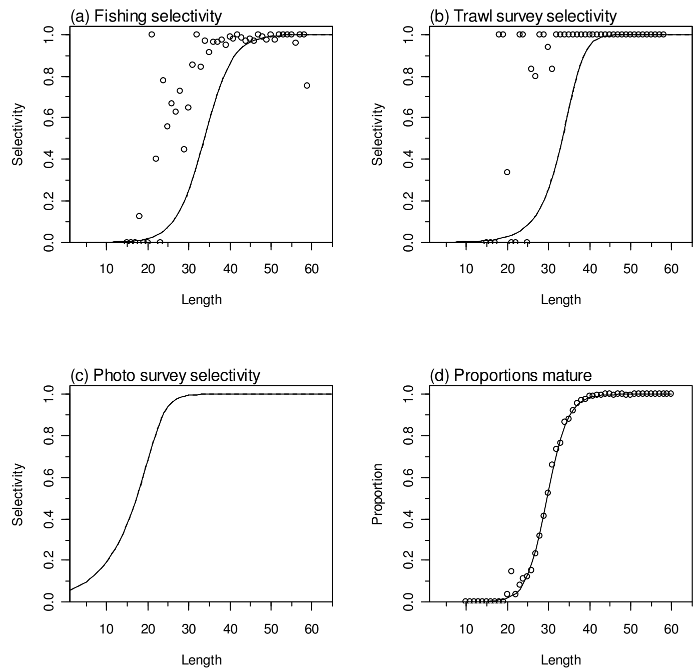

Figure 56: Fitted ogives (lines) and observed data (dots) for selectivity at length for commercial and research trawling, photographic surveys and maturity at length for SCI 1.

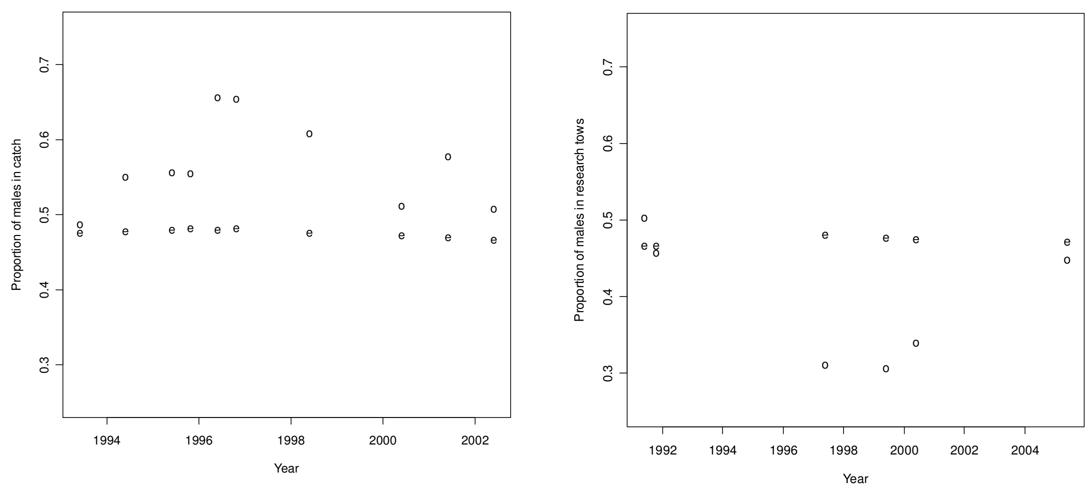

Figure 57: Observed (o) and modelled (e) proportion of males in research trawl (left) and commercial catch data (as estimated by observers, right) for SCI 1.

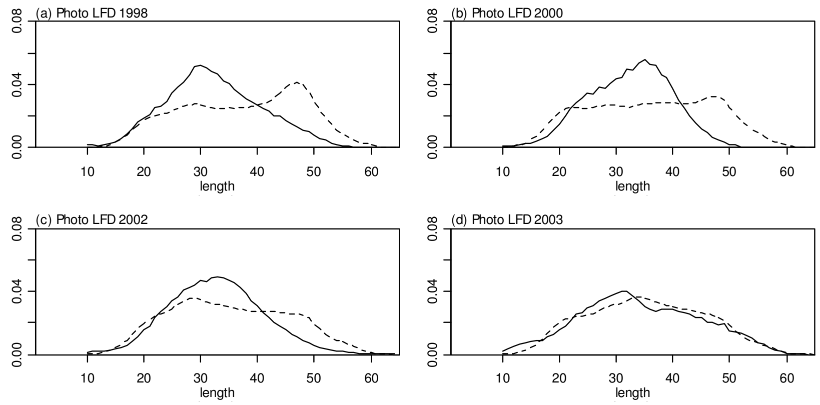

Figure 58: Observed (solid lines) and fitted (dashed lines) length frequency distributions from photographic surveys for SCI 1.

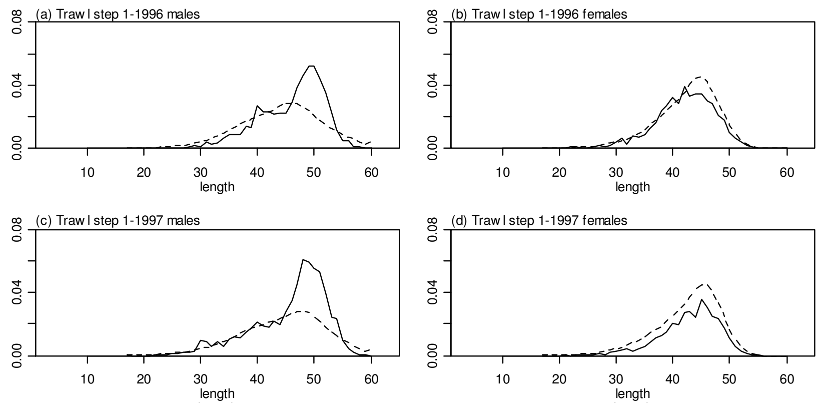

Figure 59: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 trawl surveys for SCI 1.

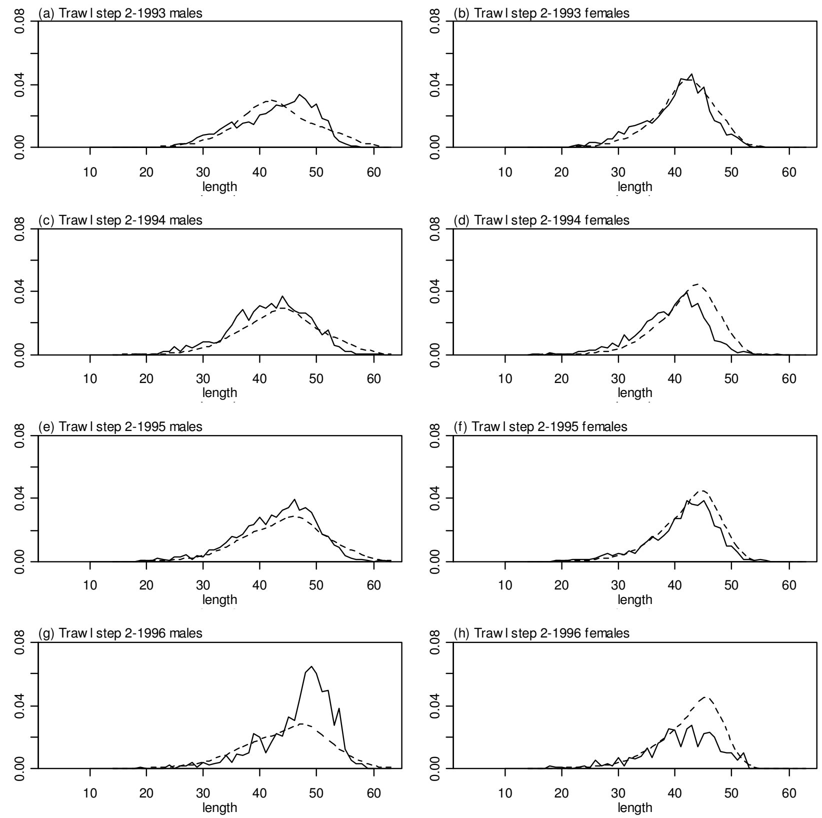

Figure 60: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys (1993-1996) for SCI 1.

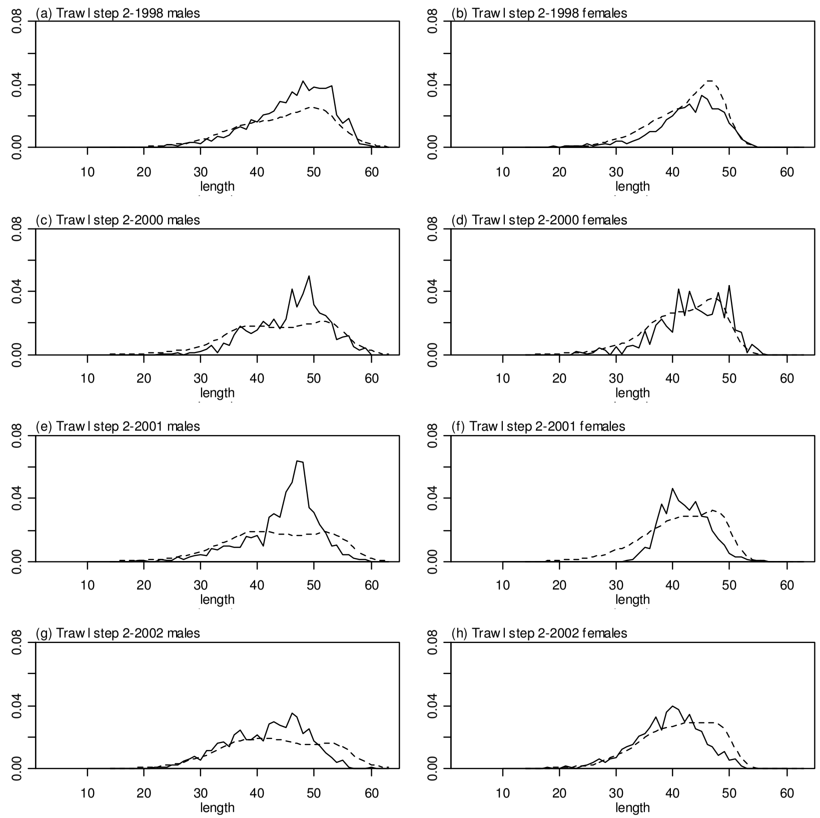

Figure 61: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys (1998-2002) for SCI 1.

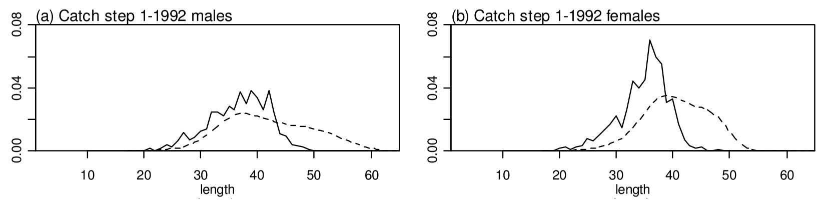

Figure 62: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 commercial catch for SCI 1.

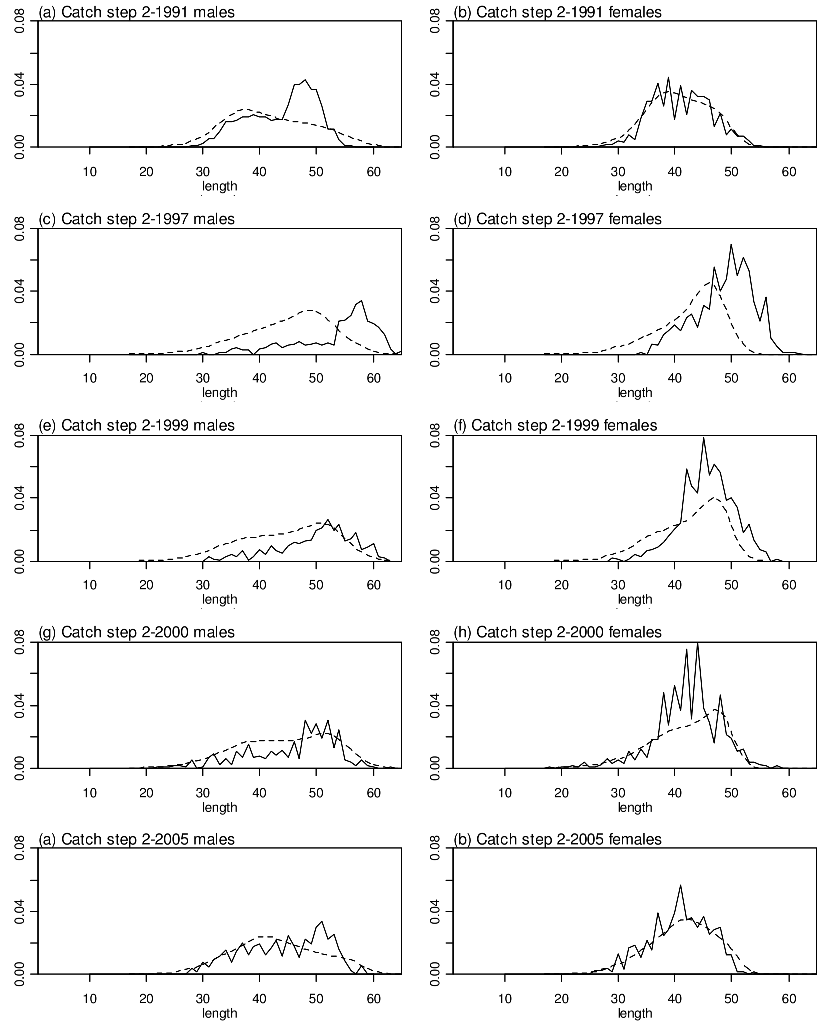

Figure 63: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 commercial catch for SCI 1.

As with the model described above, likelihood profiling of the base model (by fixing key parameters at a range of values and refitting the model at each level) suggested that a wide range of biomass levels produced similar likelihoods (the overall profile was relatively flat, Figure 64), but only a narrow range of M was tolerated (the overall profile was relatively steep, Figure 65). Note the scales are different in the plots. Additions to the likelihood components for each term are provided in Table 18. As above, the likelihood profile for B_0 did not respond strongly to any of the relative abundance data sets (CPUE, photo or trawl survey), and the proportion (and catch) at length and selectivity data provided inconsistent signals. The proportion (trawl survey) and catch (commercial) at length data from step 1 (October to December) suggests a $B_0 > 3\,000$ t, while both step 2 data sets indicate a $B_0 < 3\,000$ t. The likelihood profile for B_0 did not respond to the research trawl selectivity data, but the commercial trawl data indicated a $B_0 > 2\,000$ t. The priors for recruitment YCS and q-Photo were both influential, with the YCS constraint suggesting a $B_0 > 3\,000$ to 4 000 t, and q-Photo suggesting a value between 3 000 to 10 000 t.

The likelihood profile for M was very strongly affected by the proportion and catch at length and both research and commercial trawl selectivity data sets and to a far lesser extent by the prior for recruitment YCS, and the photo survey relative abundance index. Both trawl survey proportion at length and the catch at length for time step 1 data series suggested higher M values (> 0.25 to 0.3), while the catch at length for time step 1 suggested an M < 0.15. Both the trawl selectivity data sets suggested an M > 0.30. The prior on recruitment YCS suggested an M at about 0.24, while the photo survey index suggested an M > 0.15.

The base model was not sensitive to relaxing the prior on M or including the constraint on YCS to fit a 3rd order polynomial (Table 19). It was sensitive to the inclusion of all the observer data, the flexibility to fit process error relative to the abundance indices, excluding the CPUE and trawl survey indices (all of which decreased the estimate of B_0), applying a different prior on q-Photo, and the amount of constraint put on the recruitment variability. Applying the prior for q-Photo based on approach 1 (uniform distributions of occupancy and detection, resulting in a prior with high cv) resulted in an estimate of q-Photo of 0.14 (compared to 0.57 in the base model), with an associated increase in the estimate of B_0. Applying the prior for q-Photo based on approach 2 resulted in an estimate of q-Photo of 0.67, with an associated decrease in the estimate of B_0. Relaxing the constraint put on recruitment variability (increasing YCS cv to 0.4) decreased the estimate of B_0, while increasing the constraint (reducing YCS cv to 0.1) increased the estimate of B_0.

With the exception of the run using the prior for q-Photo based on approach 1 (and resulting in a low q-Photo and a B_0 estimate of over 26 000 t), none of the estimates of B_0 seem implausible, ranging from 4 323 to 8 373 tonnes. M appeared insensitive to the modelling choices (consistently about 0.24, except for the model with cod end data excluded – 0.29), which as discussed above, may be an artefact of the imposed growth model and observed length frequency distributions (Cryer at al. 2005), and is around the anticipated value. B_{2005} was consistently estimated to be 74 - 89% of B_0, with the extremes of this range associated with the q-Photo prior based on approach 1 and varying the constraint on recruitment variability (Table 19).

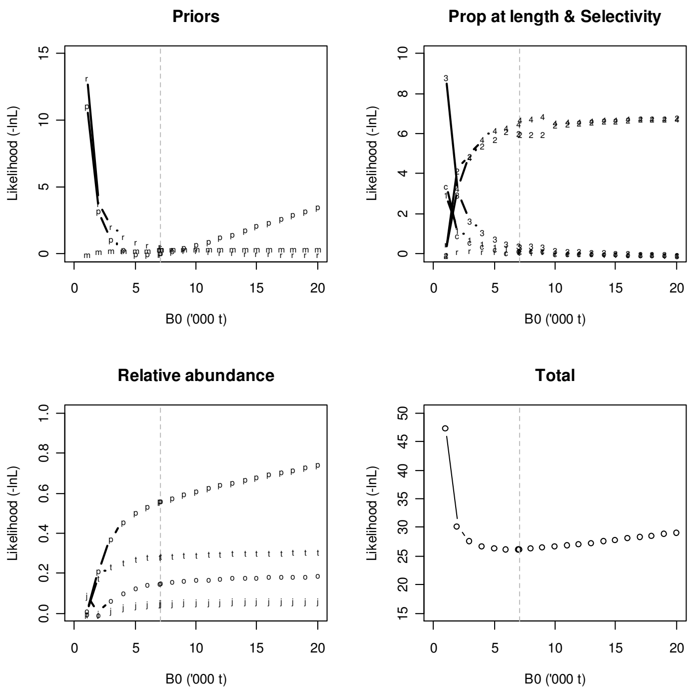

Figure 64: Likelihood profiles for the base model (N process error equal) when B_0 is fixed in the model for SCI 1. Figures show profiles for main priors (top left: p – qPhoto, r – recruitment YCS, m – natural mortality), proportion at length data (top right: 1 – trawl survey step 1, 2 – trawl survey step 2, 3 – comm observer step 1, 4 – comm observer step 2, c – selectivity of commercial trawl, r – selectivity of research trawl), relative abundance data (bottom left: j – CPUE step 1, o – CPUE step 2, p – photo survey, t – trawl survey) individually, and for the whole model (bottom right).

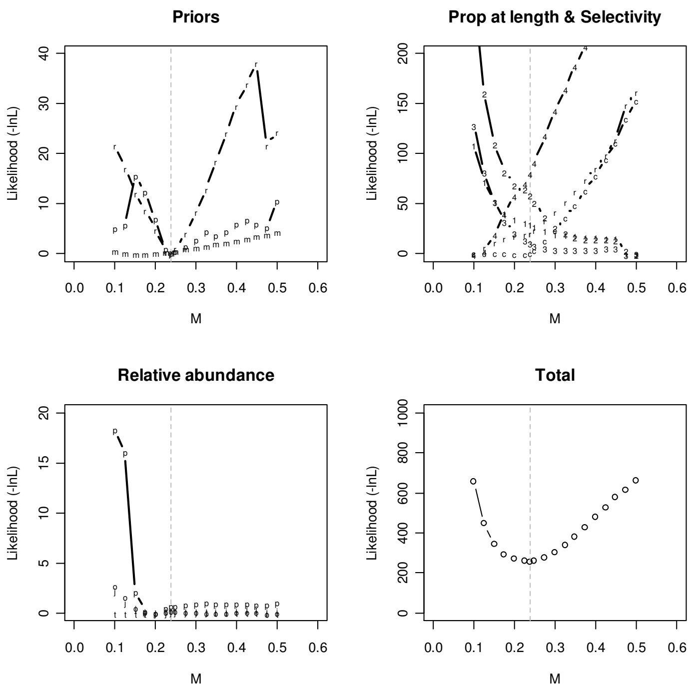

Figure 65: Likelihood profiles for the base model (N process error equal) when M is fixed in the model for SCI 1. Figures show profiles for main priors (top left: p – qPhoto, r – recruitment YCS, m – natural mortality), proportion at length data (top right: 1 – trawl survey step 1, 2 – trawl survey step 2, 3 – comm observer step 1, 4 – comm observer step 2, c – selectivity of commercial trawl, r – selectivity of research trawl), relative abundance data (bottom left: j – CPUE step 1, o – CPUE step 2, p – photo survey, t – trawl survey) individually, and for the whole model (bottom right).

Table 18: Additions to likelihood components (over and above the minimum for each) for the base model (Base (N)) for each data set and for the priors and penalties when B_0 or M are fixed at values between 1 000 and 20 000 t and 0.1 and 0.5, respectively for SCI 1. The MPD fit for the base model is in bold font.

	relative abundance				proportion at length								prior											penalty		
B_0	CPUE-Commercial-Jan	CPUE-Commercial-Oct	PhotoSurvey	TrawlSurvey	PhotoProportionAtLength-Jan	TrawlSurveyProportionAtLength-Jan	TrawlSurveyProportionAtLength-Oct	CommercialCatchLengthJan	CommercialCatchLengthOct	Cryer_Oliver_maturity	SHSP05_expt_comm	SHSP05_expt_rsch	prior_on_initialization.B0	prior_on_natural_mortality.all	prior_on_relative_abundance[PhotoSurvey].cv_process_error	prior_on_recruitment.YCS	prior_on_maturity_props.all	prior_on_selectivity[FishingSel].male	prior_on_selectivity[TrawlSurveySel].male	prior_on_selectivity[PhotoSurveySel].male	prior_on_q_CPUE-Commercialq	prior_on_q_PhotoSurveyq	prior_on_q_TrawlSurveyq	OctCatchMustBeTaken	JanCatchMustBeTaken	YCS_average_1
1.000	0.1	0.0	0.0	0.0	0.0	0.0	3.0	0.0	8.9	0.0	3.5	0.5	0.0	0.0	0.0	13.3	0.0	0.0	0.0	0.0	3.4	11.2	3.4	0.0	0.0	0.0
2.000	0.0	0.0	0.2	0.2	4.0	4.2	1.2	3.3	3.0	0.0	0.9	0.2	0.7	0.2	0.0	3.8	0.0	0.0	0.0	0.0	2.5	3.2	2.5	0.0	0.0	0.0
3.000	0.0	0.1	0.4	0.2	5.1	4.9	0.7	4.9	1.7	0.0	0.6	0.2	1.1	0.3	0.0	2.1	0.0	0.0	0.0	0.0	2.0	1.1	2.0	0.0	0.0	0.0
4.000	0.0	0.1	0.5	0.3	5.5	5.5	0.5	5.8	1.1	0.0	0.4	0.2	1.4	0.3	0.0	1.4	0.0	0.0	0.0	0.0	1.7	0.3	1.7	0.0	0.0	0.0
5.000	0.0	0.1	0.5	0.3	5.8	5.8	0.4	6.3	0.8	0.0	0.2	0.2	1.6	0.3	0.0	0.9	0.0	0.0	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0
6.000	0.0	0.1	0.5	0.3	6.2	6.2	0.3	6.3	0.6	0.0	0.1	0.1	1.8	0.4	0.0	0.7	0.0	0.0	0.0	0.0	1.2	0.0	1.2	0.0	0.0	0.0
7.000	0.1	0.2	0.6	0.3	6.2	6.1	0.2	6.6	0.5	0.0	0.2	0.2	1.9	0.4	0.0	0.6	0.0	0.0	0.0	0.0	1.1	0.1	1.1	0.0	0.0	0.0
7.133	**0.1**	**0.2**	**0.6**	**0.3**	**6.2**	**6.0**	**0.3**	**6.7**	**0.4**	**0.0**	**0.2**	**0.1**	**2.0**	**0.4**	**0.0**	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**	**1.1**	**0.1**	**1.1**	**0.0**	**0.0**	**0.0**
8.000	0.1	0.2	0.6	0.3	6.2	6.0	0.2	6.8	0.5	0.0	0.2	0.2	2.1	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.9	0.3	0.9	0.0	0.0	0.0
9.000	0.1	0.2	0.6	0.3	6.3	6.0	0.2	6.9	0.4	0.0	0.2	0.2	2.2	0.4	0.0	0.3	0.0	0.0	0.0	0.0	0.8	0.5	0.8	0.0	0.0	0.0
10.000	0.1	0.2	0.6	0.3	6.7	6.5	0.1	6.6	0.3	0.0	0.1	0.1	2.3	0.4	0.0	0.3	0.0	0.0	0.0	0.0	0.7	0.7	0.7	0.0	0.0	0.0
11.000	0.1	0.2	0.6	0.3	6.7	6.6	0.1	6.6	0.2	0.0	0.1	0.1	2.4	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.6	1.0	0.6	0.0	0.0	0.0
12.000	0.1	0.2	0.6	0.3	6.8	6.6	0.1	6.7	0.2	0.0	0.1	0.1	2.5	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.5	1.2	0.5	0.0	0.0	0.0
13.000	0.1	0.2	0.7	0.3	6.8	6.7	0.1	6.7	0.1	0.0	0.1	0.1	2.6	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.4	1.5	0.4	0.0	0.0	0.0
14.000	0.1	0.2	0.7	0.3	6.9	6.7	0.0	6.8	0.1	0.0	0.0	0.0	2.6	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.4	1.8	0.4	0.0	0.0	0.0
15.000	0.1	0.2	0.7	0.3	6.9	6.7	0.0	6.8	0.1	0.0	0.0	0.0	2.7	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.3	2.1	0.3	0.0	0.0	0.0
16.000	0.1	0.2	0.7	0.3	6.9	6.8	0.0	6.8	0.1	0.0	0.0	0.0	2.8	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.2	2.4	0.2	0.0	0.0	0.0
17.000	0.1	0.2	0.7	0.3	7.0	6.8	0.0	6.8	0.0	0.0	0.0	0.0	2.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.7	0.2	0.0	0.0	0.0
18.000	0.1	0.2	0.7	0.3	7.0	6.8	0.0	6.8	0.0	0.0	0.0	0.0	2.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.0	0.1	0.0	0.0	0.0
19.000	0.1	0.2	0.7	0.3	7.0	6.8	0.0	6.8	0.0	0.0	0.0	0.0	2.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.2	0.1	0.0	0.0	0.0
20.000	0.1	0.2	0.7	0.3	7.1	6.9	0.0	6.8	0.0	0.0	0.0	0.0	3.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0
M																										
0.100	2.2	2.7	18.3	0.0	96.2	261.6	108.8	0.0	128.6	0.0	1.5	0.0	0.0	0.7	0.0	21.6	0.0	0.0	0.0	0.0	3.9	5.0	3.9	0.0	0.0	0.0
0.125	1.1	1.6	16.0	0.0	70.2	161.0	73.0	2.6	82.0	0.0	1.0	6.3	0.0	0.2	0.0	17.2	0.0	0.0	0.0	0.0	3.8	5.7	3.8	0.0	0.0	0.0
0.150	0.4	0.6	2.1	0.0	56.6	110.0	53.2	19.2	52.5	0.0	0.8	11.7	0.0	0.0	0.0	12.1	0.0	0.0	0.0	0.0	3.6	15.5	3.6	0.0	0.0	0.0
0.175	0.1	0.1	0.2	0.1	49.9	82.0	41.5	40.3	33.4	0.0	0.9	15.8	0.1	0.0	0.0	8.8	0.0	0.0	0.0	0.0	3.3	12.3	3.4	0.0	0.0	0.0
0.200	0.0	0.0	0.0	0.2	48.3	70.0	35.3	57.5	21.2	0.0	0.3	17.9	0.4	0.2	0.0	4.8	0.0	0.0	0.0	0.0	2.8	7.0	2.9	0.0	0.0	0.0
0.225	0.0	0.2	0.4	0.3	48.6	65.3	31.7	70.9	13.9	0.0	0.0	19.6	1.3	0.4	0.0	0.4	0.0	0.0	0.0	0.0	1.8	0.9	1.9	0.0	0.0	0.0
0.239	**0.1**	**0.3**	**0.6**	**0.3**	**45.7**	**59.2**	**29.5**	**81.2**	**10.8**	**0.0**	**1.7**	**21.2**	**2.1**	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.9**	**0.0**	**1.0**	**0.0**	**0.0**	**0.0**
0.250	0.1	0.2	0.7	0.3	40.9	52.0	27.6	91.5	9.2	0.0	4.7	23.7	2.4	0.7	0.0	1.1	0.0	0.0	0.0	0.0	0.6	0.5	0.7	0.0	0.0	0.0
0.275	0.1	0.2	0.8	0.3	30.0	36.8	23.2	118.4	6.2	0.0	13.6	33.1	2.7	1.0	0.0	4.2	0.0	0.0	0.0	0.0	0.4	1.5	0.5	0.0	0.0	0.0
0.300	0.1	0.2	0.9	0.2	21.9	27.1	20.5	143.5	4.9	0.0	23.8	42.4	2.9	1.3	0.0	8.3	0.0	0.0	0.0	0.0	0.2	2.8	0.2	0.0	0.0	0.0
0.325	0.2	0.1	1.0	0.2	15.6	21.2	19.1	165.8	4.6	0.0	36.3	52.1	3.2	1.7	0.0	12.9	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0
0.350	0.2	0.1	0.9	0.1	10.6	17.3	18.0	188.8	4.4	0.0	49.3	63.1	3.0	2.0	0.0	18.6	0.0	0.0	0.0	0.0	0.3	3.6	0.2	0.0	0.0	0.0
0.375	0.3	0.1	0.9	0.1	7.0	15.6	17.4	208.4	4.8	0.0	63.6	74.3	3.1	2.4	0.0	24.2	0.0	0.0	0.0	0.0	0.3	4.3	0.2	0.0	0.0	0.1
0.400	0.3	0.1	0.9	0.1	4.6	15.0	16.9	226.0	5.3	0.0	78.6	86.2	3.4	2.8	0.0	29.6	0.0	0.0	0.0	0.0	0.1	5.8	0.1	0.0	0.0	0.1
0.425	0.4	0.1	0.9	0.1	2.8	15.2	16.7	242.2	6.1	0.0	94.9	99.0	3.5	3.2	0.0	34.1	0.0	0.0	0.0	0.0	0.2	6.6	0.0	0.0	0.0	0.2
0.450	0.5	0.2	0.8	0.1	1.8	14.6	15.8	258.9	6.1	0.0	111.8	114.3	3.4	3.6	0.0	38.1	0.0	0.0	0.0	0.0	0.4	5.8	0.3	0.0	0.0	0.3
0.475	0.2	0.0	0.8	0.0	0.0	3.8	1.2	288.5	0.0	0.0	135.4	149.0	3.1	4.0	0.0	21.7	0.0	0.0	0.0	0.0	0.8	5.3	0.7	0.0	0.0	0.1
0.500	0.3	0.0	1.0	0.0	0.8	0.0	0.0	298.1	0.8	0.0	153.1	161.4	3.8	4.4	0.0	24.5	0.0	0.0	0.0	0.0	0.3	10.5	0.2	0.0	0.0	0.1

Table 19: Estimated parameters and quantities from the base case and sensitivity MPD fits for the SCI 1 modelled area (N process error on proportion at length and catch at length equal).

Estimated parameters	Base (N)	Base (N, PE)	All_obs	NoCPUE	NoCPUE/TRAWL	NoCodEnd	q-Photo 1	q-Photo 2	FreeM	cvYCS10%	cvYCS40%	YCS smoothing	YCS smooth & cv10%	YCS smooth & cv40%
initialization.B0	7133	5718	5887	5109	4323	6584	26680	6139	7172	8373	4046	6768	8342	4788
natural_mortality.all	0.239	0.238	0.240	0.237	0.236	0.293	0.243	0.238	0.240	0.236	0.240	0.239	0.236	0.242
PhotoSurvey.cv_process_error	0.109	0.104	0.122	0.105	0.103	0.123	0.113	0.107	0.109	0.119	0.079	0.123	0.124	0.112
CPUE-Commercialq	0.0073	0.0074	0.0092			0.0131	0.0019	0.0086	0.0073	0.0063	0.0132	0.0077	0.0063	0.0109
PhotoSurveyq	0.5752	0.7270	0.6924	0.8154	0.9735	0.5262	0.1475	0.6732	0.5716	0.4696	1.0767	0.6184	0.4747	0.9149
TrawlSurveyq	0.0017	0.0018	0.0021	0.0024		0.0023	0.0004	0.0020	0.0017	0.0015	0.0030	0.0018	0.0015	0.0025
R0	6.24E+07	4.95E+07	5.16E+07	4.38E+07	3.66E+07	8.87E+07	2.41E+08	5.32E+07	6.29E+07	7.08E+07	3.55E+07	5.92E+07	7.06E+07	4.27E+07
YCS_1985	1.15	1.17	1.27	1.16	1.16	0.96	1.13	1.15	1.15	1.05	1.49	1.07	1.01	1.17
YCS_1986	1.24	1.25	1.28	1.25	1.25	1.11	1.22	1.24	1.24	1.20	1.04	1.64	1.38	1.72
YCS_1987	2.20	2.22	2.12	2.20	2.22	2.24	2.16	2.19	2.19	1.62	2.51	1.76	1.48	1.81
YCS_1988	1.74	1.76	1.64	1.74	1.74	1.80	1.73	1.74	1.74	1.53	1.76	1.59	1.40	1.60
YCS_1989	1.04	1.06	1.01	1.05	1.05	0.97	1.04	1.05	1.04	1.10	0.96	1.29	1.22	1.27
YCS_1990	1.01	1.02	0.95	1.01	1.01	0.96	1.01	1.01	1.01	1.01	0.98	1.01	1.02	0.96
YCS_1991	0.88	0.88	0.79	0.87	0.87	0.93	0.87	0.87	0.88	0.91	0.84	0.80	0.88	0.73
YCS_1992	0.67	0.67	0.62	0.67	0.67	0.70	0.67	0.67	0.67	0.78	0.58	0.69	0.79	0.61
YCS_1993	0.66	0.66	0.63	0.66	0.66	0.68	0.66	0.66	0.66	0.76	0.60	0.64	0.76	0.57
YCS_1994	0.64	0.64	0.64	0.64	0.64	0.66	0.64	0.64	0.64	0.76	0.56	0.65	0.76	0.57
YCS_1995	0.68	0.67	0.68	0.68	0.68	0.70	0.68	0.67	0.68	0.79	0.57	0.67	0.78	0.59
YCS_1996	0.80	0.80	0.83	0.80	0.80	0.84	0.81	0.80	0.80	0.86	0.77	0.71	0.82	0.62
YCS_1997	0.69	0.69	0.72	0.69	0.69	0.75	0.70	0.69	0.69	0.83	0.56	0.76	0.87	0.66
YCS_1998	0.79	0.78	0.83	0.78	0.78	0.78	0.79	0.79	0.79	0.91	0.68	0.83	0.93	0.72
YCS_1999	0.94	0.93	1.00	0.94	0.94	0.93	0.96	0.94	0.94	1.02	0.79	0.91	0.99	0.80
YCS_2000	1.16	1.15	1.17	1.16	1.15	1.08	1.17	1.16	1.16	1.10	1.13	0.97	1.03	0.86
YCS_2001	0.86	0.85	0.88	0.86	0.85	0.89	0.87	0.86	0.86	0.96	0.69	0.98	1.02	0.88
YCS_2002	0.93	0.92	0.97	0.93	0.92	1.04	0.94	0.93	0.93	0.97	0.82	0.95	0.99	0.84
YCS_2003	0.90	0.89	0.91	0.89	0.89	0.92	0.90	0.89	0.90	0.97	0.72	0.90	0.96	0.77
YCS_2004	0.89	0.89	0.89	0.89	0.89	0.86	0.89	0.89	0.89	0.97	0.69	0.87	0.97	0.67
Maturity50	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18
MaturityTo95	7.34	7.34	7.35	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34
Comm50	34.28	34.29	34.85	34.27	34.30	43.07	34.21	34.25	34.29	34.08	34.31	34.09	33.96	34.10
CommTo95	10.19	10.13	10.47	10.11	10.17	15.66	10.04	10.09	10.19	9.71	10.48	9.69	9.43	9.85
CommAsy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rsch50	33.87	33.86	33.90	33.89	33.90	38.55	33.87	33.89	33.88	34.58	33.55	33.92	34.62	33.57
RschTo95	6.70	6.73	6.41	6.72	6.78	12.58	6.61	6.67	6.72	7.43	6.18	7.12	7.56	7.18
RschAsy	2.28	2.27	2.44	2.28	2.25	1.00	2.33	2.31	2.27	2.01	2.59	2.09	1.97	1.99
Photo50	17.53	17.56	17.90	17.60	17.51	20.27	17.83	17.78	17.56	17.85	16.98	18.51	18.14	18.64
PhotoTo95	8.36	8.29	8.42	8.28	8.37	7.87	8.08	8.15	8.36	7.91	8.75	7.52	7.69	6.70
PhotoAsy	4.00	3.75	3.21	3.71	3.69	3.35	3.74	3.71	3.95	4.05	3.49	4.39	4.33	9.99
B2005	5903	4617	4861	4104	3402	5494	23330	5018	5936	7416	2988	5548	7368	3616
B2005/B1985	0.83	0.81	0.83	0.80	0.79	0.83	0.87	0.82	0.83	0.89	0.74	0.82	0.88	0.76

3.2 SCI 1 model development

The complete down weighting of the commercial catch at length data in the model with N process error fitted externally implies that the commercial observer data is completely inconsistent with the rest of the available data when considered within the existing model structure. This would suggest that either that there is some fundamental flaw with the way the data are collected and raised, or that the model structure does not appropriately reflect how the catch data relate to the population.

Examination of the base model likelihood profile plots (Figure 51, Figure 52, Figure 64 and Figure 65) suggest that the proportion and catch at length data from the two time steps in the model may be providing contrasting information about both the B_0 and M. Scampi CPUE has been observed to vary on a seasonal basis (Vignaux and Gilbert, 1994), and strong seasonal patterns in CPUE have been identified for *Nephrops*, interpreted as fluctuations in burrow emergence in relation to reproductive (particularly for females) and moult cycles (Bell et al., 2006). It is very likely that the CPUE patterns observed in New Zealand scampi are related to variability in burrow emergence (and hence catchability), in relation to reproductive behaviour. Within the model, the length structure of the population is linked to the proportions at length in the catches through the selectivity ogives, and if availability at length varies seasonally and with sex (because of reduced emergence of ovigerous mature females, for example), then allowing selectivity to vary between time steps or sexes may be appropriate. As employed within the model, the selectivity term represents availability to the fishing gear, rather than fishing gear selectivity. Although not examined here, the fact that the selectivity term effectively measures availability to the fishery (or survey) may suggest that other ogives available within CASAL allowing reduced availability at increased lengths (such as variations on Double-normal or Hillary) may also merit consideration in the future, as more data become available. As discussed in section 2.2.2, alternative approaches to addressing scampi growth within the model may also be more appropriate that those in the base model. Therefore, model development investigations were conducted, examining these changes to the model structure (summarised in Table 20). These have been based on the model structure with equal N process error for research and commercial length data to allow investigation of the effects, since the down weighting of the commercial data (in the approach with N process error fitted externally) may potentially negate any effect of allowing selectivity to vary.

Table 20: Summary of development runs

Model	Description
Base (N)	Base model, photo survey as numbers, informative priors on M and q-Photo, YCS cv = 0.20
2 stage growth	Same as base (N) with maturation partition and revised growth approach (section 2.2.2)
Selectivity by time step	Same as base (N) with selectivity for research and commercial trawl allowed to vary between time step
Selectivity by sex	Same as base (N) with selectivity for research and commercial trawl allowed to vary between sex
2 stage growth & selectivity by time step	Same as base (N) with maturation partition and revised growth approach (section 2.2.2) and selectivity for research and commercial trawl allowed to vary between time step
2 stage growth & selectivity by time step (no cod end)	Same as base (N) with maturation partition and revised growth approach (section 2.2.2) and selectivity for research and commercial trawl allowed to vary between time step, and model not fitted to cod-end selectivity data
Selectivity by time step & sex	Same as base (N) with selectivity for research and commercial trawl allowed to vary between time step and sex
2 stage growth & selectivity by time step & sex	Same as base (N) with maturation partition and revised growth approach (section 2.2.2) and selectivity for research and commercial trawl allowed to vary between time step and sex

Estimated parameters from each of the development runs are presented in Table 21. With the exception of model that failed to converge, none of the fits seem implausible, although allowing selectivity to vary (by time step or sex) without altering the growth approach resulted in B_0 estimates towards the lower end of the range observed in the earlier sensitivity runs (Table 19).

Table 21: Estimated parameters and quantities from the base case and sensitivity MPD fits for the SCI 1 modelled area (N process error on proportion at length and catch at length equal). Where selectivity was allowed to vary with time step or sex, the parameters for time step 2 are presented below time step 1, and parameters for females are presented immediately to the right of those for the males. Fit in italics (2 stage growth & selectivity varying by time step and sex, with cod end data not included) did not converge.

		Base (N)	2 stage growth	Selectivity by time step	Selectivity by sex		2 stage growth & selectivity by time step	2 stage growth & selectivity by time step (no cod end data)	Selectivity by time step and sex		2 stage growth & selectivity by time step and sex		*2 stage growth & selectivity by time step and sex (no cod end data)*	
	initialization.B0	7133	6703	4523	2816		6835	6936	3248		5841		*20925*	
	natural_mortality.all	0.24	0.24	0.25	0.22		0.23	0.28	0.23		0.22		*0.35*	
	PhotoSurvey.cv_process_error	0.11	0.11	0.11	0.08		0.12	0.13	0.09		0.10		*0.16*	
	CPUE-Commercialq	0.01	0.01	0.01	0.02		0.01	0.01	0.02		0.01		*0.01*	
	PhotoSurveyq	0.58	0.65	0.88	1.66		0.63	0.54	1.34		0.78		*0.16*	
	TrawlSurveyq	0.00	0.00	0.00	0.00		0.00	0.00	0.00		0.00		*0.00*	
	R0	6.24E+07	5.76E+07	4.37E+07	2.10E+07		5.57E+07	8.11E+07	2.73E+07		4.33E+07		*3.97E+08*	
	YCS_1985	1.15	1.10	1.11	1.24		1.09	0.97	1.18		1.14		*1.00*	
	YCS_1986	1.24	1.28	1.20	1.34		1.42	1.31	1.28		1.48		*1.30*	
	YCS_1987	2.20	2.68	2.34	2.51		2.53	2.40	2.37		2.74		*2.15*	
	YCS_1988	1.74	1.33	1.50	1.68		1.05	0.96	1.59		1.09		*0.92*	
	YCS_1989	1.04	1.03	0.84	1.06		0.79	0.75	0.88		0.80		*0.79*	
	YCS_1990	1.01	1.06	1.02	1.05		1.08	1.05	1.04		1.08		*1.11*	
	YCS_1991	0.88	0.83	0.91	0.89		0.89	0.89	0.97		0.88		*0.93*	
	YCS_1992	0.67	0.65	0.72	0.66		0.72	0.74	0.75		0.72		*0.79*	
	YCS_1993	0.66	0.67	0.71	0.66		0.69	0.70	0.72		0.70		*0.72*	
	YCS_1994	0.64	0.65	0.65	0.64		0.67	0.71	0.63		0.68		*0.70*	
	YCS_1995	0.68	0.73	0.68	0.68		0.73	0.76	0.66		0.72		*0.76*	
	YCS_1996	0.80	0.78	0.84	0.80		0.83	0.88	0.82		0.83		*0.89*	
	YCS_1997	0.69	0.69	0.72	0.65		0.70	0.75	0.69		0.68		*0.75*	
	YCS_1998	0.79	0.82	0.79	0.73		0.82	0.82	0.74		0.77		*0.82*	
	YCS_1999	0.94	1.02	0.91	0.89		0.98	1.00	0.86		0.92		*0.98*	
	YCS_2000	1.16	1.09	1.11	1.14		1.11	1.09	1.10		1.10		*1.05*	
	YCS_2001	0.86	0.83	0.88	0.83		0.87	0.95	0.83		0.86		*0.95*	
	YCS_2002	0.93	0.94	1.04	0.86		1.04	1.16	0.94		0.99		*1.22*	
	YCS_2003	0.90	0.87	1.00	0.82		0.95	0.97	0.92		0.88		*0.95*	
	YCS_2004	0.89	0.90	0.91	0.85		0.92	0.91	0.88		0.88		*0.92*	
	Maturity50	30.18	25.41	30.18	30.18		25.36	25.30	30.18		25.37		*25.19*	
	MaturityTo95	7.34	12.20	7.34	7.34		11.52	11.42	7.34		11.54		*11.25*	
time step 1	Comm50	34.28	34.33	26.36	35.00	31.91	25.90	26.61	28.12	25.32	25.90	25.26	*29.06*	*27.66*
time step 1	CommTo95	10.19	10.01	4.04	12.36	7.13	3.36	3.65	5.57	3.31	2.99	3.26	*4.72*	*4.03*
time step 1	CommAsy	1.00	1.00	2.04	1.00	1.86	2.13	2.05	1.90	2.14	1.92	2.11	*1.90*	*2.05*
time step 1	Rsch50	33.87	33.86	39.81	32.57	33.21	39.03	42.93	39.53	44.51	37.24	39.76	*46.17*	*46.71*
time step 1	RschTo95	6.70	6.85	12.95	5.78	5.74	12.15	13.31	9.30	21.03	9.17	13.60	*7.27*	*13.07*
time step 1	RschAsy	2.28	2.06	1.00	2.60	3.56	1.00	1.02	1.83	1.00	1.56	1.00	*2.93*	*1.04*
time step 2	Comm50			38.12			37.71	45.46	37.82	35.09	38.95	32.38	*60.00*	*52.01*
time step 2	CommTo95			11.00			10.84	13.98	13.04	6.43	15.53	5.45	*7.55*	*5.90*
time step 2	CommAsy			1.00			1.02	1.00	1.02	2.64	1.00	3.10	*3.29*	*3.38*
time step 2	Rsch50			34.12			34.13	37.58	32.68	33.21	35.66	33.30	*41.90*	*41.98*
time step 2	RschTo95			6.11			5.53	11.52	5.43	5.74	5.45	5.51	*12.68*	*13.20*
time step 2	RschAsy			2.80			3.53	1.00	3.01	3.71	3.68	3.95	*1.06*	*1.00*
	Photo50	17.53	19.32	18.53	16.86		18.56	20.71	17.57		17.79		*23.18*	
	PhotoTo95	8.36	6.79	8.13	8.45		7.14	7.22	8.32		7.58		*8.32*	
	PhotoAsy	4.00	3.63	3.55	3.43		3.89	3.75	3.50		3.51		*3.28*	
	B2005	5903	5511	3609	1999		5717	6030	2401		4715		*19190*	
	B2005/B1985	0.83	0.82	0.80	0.71		0.84	0.87	0.87		0.87		*0.87*	

In the models allowing selectivity to vary with time step, L_{50} was consistently higher in the second time step for commercial trawl, but in the first time step for research trawl. Where selectivity was allowed to vary between sex, L_{50} was generally higher for males for commercial trawl, but higher for females for research trawl. These apparent inconsistencies may relate to the specific timing of the data series. The time steps run from October to December (time step 1) and January to September (time step 2). The patchy nature of the sampling of scampi catches both spatially and temporally, make investigation of the seasonal patterns difficult (although this will be investigated in SCI2006-01). Research trawling has mostly been conducted between January and March / April. In *Nephrops* fisheries (northern hemisphere), the main drivers to patterns in sex and size distribution are considered to be the reproductive cycle (mature [larger] females being far more available to the fishery in late summer [July - August], between one set of eggs hatching and the next being spawned onto the pleopods), and recruitment into the fishery (typically in winter [December to March] as discards, 15-20 mm OCL, but depending on mesh size and growth). Recruitment dynamics may not be the same for *Metanephrops* as the recruitment strategy appears to be different (lower fecundity with apparently very short or absent larval phase), and animals enter the fishery at a larger size, but if the reproductive cycle patterns were shifted by 6 months for New Zealand scampi, then the greatest availability of mature females would be expected in the January – February period. This period has been targeted by the trawl surveys, while commercial data from time step 2 is combined from any samples over the period from January to September, which may account for some of the variability between years in the length frequency distributions, and the poor fit between observed and expected sex ratio. Month was a significant term in the regression tree analysis of the commercial length frequency distribution data (Figure 15).

Table 22: Components of objective function for MPD of base model (N process error on proportion at length and catch at length equal), and objective function gain (reduction) for each component for model development runs for SCI 1.

	Base (N)	2 stage growth	Selectivity by time step	Selectivity by sex	2 stage growth & selectivity by time step	2 stage growth & selectivity by time step (no cod end data)	Selectivity by time step and sex	2 stage growth & selectivity by time step and sex
prior_on_initialization.B0	9			1			1	
CommercialCatchLengthJan	1090	13	36	4	47	7	40	75
CommercialCatchLengthOct	228	7	59	11	67	83	56	66
TrawlSurveyProportionAtLength-Jan	1085	54	12	-8	66	96	2	51
TrawlSurveyProportionAtLength-Oct	296	26	18	-2	44	55	30	47
PhotoProportionAtLength-Jan	298	-5	11	-9	7	32	-1	-4
CPUE-Commercial-Jan	0					-1		
CPUE-Commercial-Oct	0					-1		
Cryer_Oliver_maturity	49	-3			-3	-3		-3
prior_on_q_CPUE-Commercialq	-5			-1			-1	
prior_on_q_PhotoSurveyq	0			-1			-1	
prior_on_q_TrawlSurveyq	-6			-1			-1	
prior_on_recruitment.YCS	24		3	-5	2	6		-1
SHSP05_expt_comm	60	3	-37	-44	-32	NA	-88	-97
SHSP05_expt_rsch	55	1	-1	-37	1	NA	-36	-34
prior_on_maturity_props.all	0	NA			NA	NA		NA
prior_on_maturation[1].rates_all	NA	NA			NA	NA		NA
prior_on_selectivity[FishingSel].male	0		NA		NA	NA	NA	NA
prior_on_selectivity[FishingSel].female	NA			NA				
prior_on_selectivity[FishingSel1].male	NA		NA		NA	NA	NA	NA
prior_on_selectivity[FishingSel1].female	NA						NA	NA
prior_on_selectivity[FishingSel2].male	NA		NA		NA	NA	NA	NA
prior_on_selectivity[FishingSel2].female	NA						NA	NA
prior_on_selectivity[TrawlSurveySel].male	0		NA		NA	NA	NA	NA
prior_on_selectivity[TrawlSurveySel].female	NA			NA				
prior_on_selectivity[TrawlSurveySel1].male	NA		NA		NA	NA	NA	NA
prior_on_selectivity[TrawlSurveySel1].female	NA						NA	NA
prior_on_selectivity[TrawlSurveySel2].male	NA		NA		NA	NA	NA	NA
prior_on_selectivity[TrawlSurveySel2].female	NA						NA	NA
Total	3174	96	102	-91	199	387	1	100

Altering the growth approach and allowing the model to vary selectivity with time step (in particular) and sex improved the fit to the proportion and catch at length data (as measured by the component objective function gain; Table 22), although the fit to the commercial data remained relatively poor. Estimating the N process error from the model outputs continued to suggest that far more weight should be put on the research trawl proportion at length data, but the estimated sample size for the commercial catch at length data was greater than in the models using the original growth and selectivity approach (section 3.1.2), indicating that the commercial data are more consistent with the other data and model structure in these revised models. The fit to the observed sex ratio in the research data was improved by the model developments (measured as average absolute difference in proportion males between observed and estimated data), while the fit to the commercial data was slightly worse (not shown).

3.3 SCI 2 base model

A model was developed for SCI 2 following the approach described in section 3.1. Sensitivities were investigated as described in Table 15. In addition, in order to be able to include survey data (photo survey abundance, research trawl abundance and research trawl proportion at length) from the survey in March / April 2006, fishery landings for the 2006 time steps were required. A TCEPR extraction has not been conducted for the 2005/06 fishing year (discussions with MFish Clients Services suggested the database may not be complete at the time of writing), and so landings for 2006 were assumed to be the same as 2005 (although the sensitivities to this were also investigated, by a) setting landings in 2006 to zero and b) setting landings in 2006 to double the 2005 landings in each time step).

The base model MPD fit with the photo survey index used as numbers (Base (N); photo survey as numbers) suggests an unexploited biomass (B_0) of about 2 600 t (Figure 66 and Table 24), and an instantaneous rate of natural mortality (M) of about 0.24 yr^{-1}. Year class strengths were estimated to have been consistently good in the late 1980’s, below-average in the mid 1990’s but closer to average in more recent years (Figure 66). Spawning stock biomass remained stable at about B_0 until the early 1990’s, declined steadily (falling to less than half the B_0 value) until 2002, but showing an increase in the most recent years. The 2005 spawning biomass was estimated to be about 51% of the unexploited biomass.

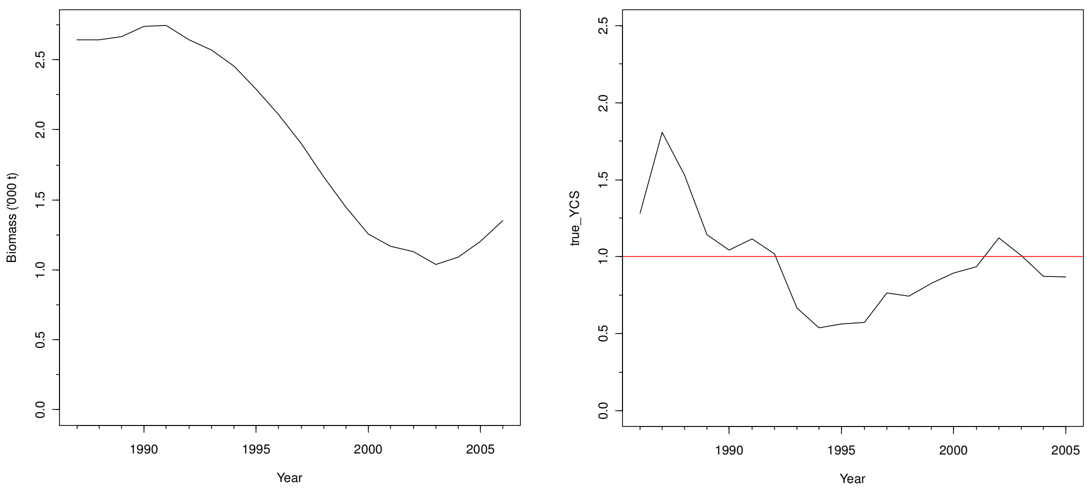

Figure 66: Base case trajectory of spawning stock biomass and year-class strength for the modelled part of the SCI 2 scampi fishery.

Model fits

As with SCI 1, none of the models examined fitted all the data well. Fits to the commercial CPUE (Figure 67) were poor, with the model unable to recreate the peak observed in each of the indices in the mid 1990’s. The fit to the research trawl abundance index (Figure 68) was better, with the general trend in the observations replicated, although the decline in the index estimated by smaller than that observed. The fit to the short photo survey series was also poor. The fits to the commercial trawl fishing selectivity (Figure 69a) and proportion mature (Figure 69d) were very good, but neither had any consequence for the model as the catch at length data were heavily down weighted by the externally fitted N process error, and fitting the maturity ogive does not require compromises to be made in other fits. Research trawl selectivity fits were poor (Figure 69b), with the model preferring far larger values of L_{50} than observed. As discussed above (section 3.1.1) scampi selectivity might not be expected to fit cod end selectivity particularly well. As with the SCI 1 base model, the fitted selectivity ogive for photographic sampling (Figure 69c) suggests that burrows of very small (< 10 mm OCL) animals were recorded, which seems unlikely.

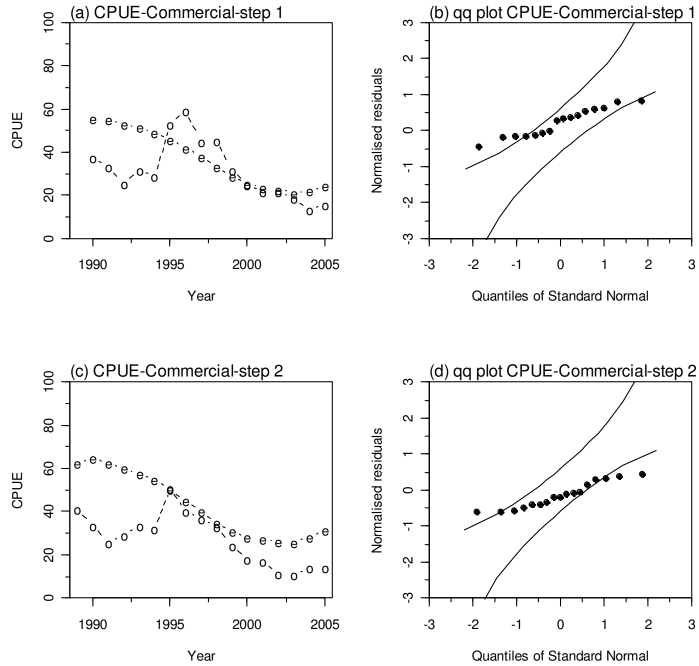

Figure 67: Fits and q-q diagnostic plots to CPUE indices for SCI 2 (o – observed, e – estimated).

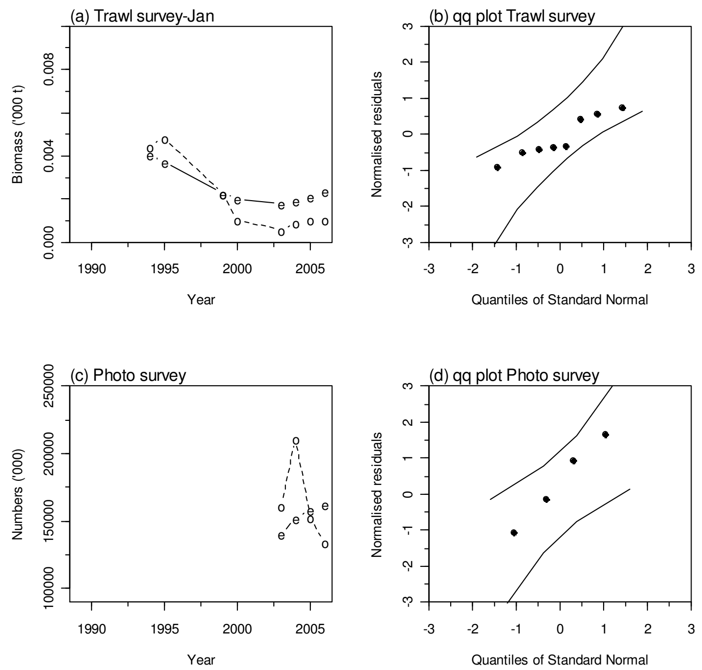

Figure 68: Fits and q-q diagnostic plots to Trawl (January) and Photo survey indices for SCI 2 (o – observed, e – estimated). A trawl survey October series is also included in the model, but only includes two points and is not plotted.

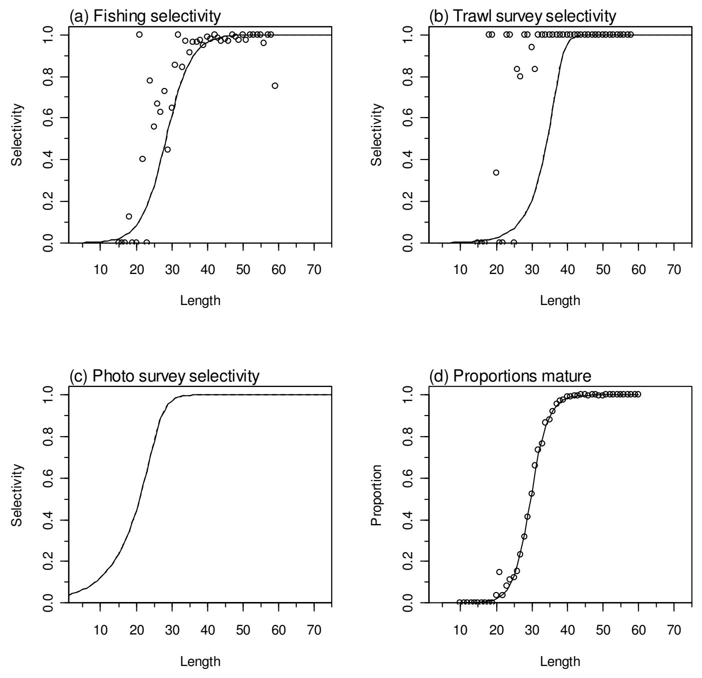

Figure 69: Fitted ogives (lines) and observed data (dots) for selectivity at length for commercial and research trawling, photographic surveys and maturity at length for SCI 2.

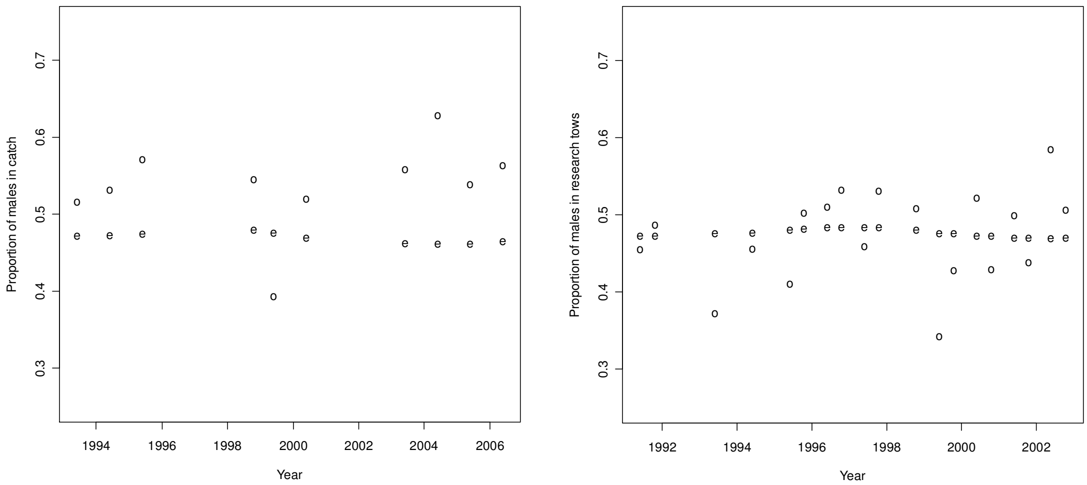

Figure 70: Observed (o) and modelled (e) proportion of males in research trawl (left) and commercial catch data (as estimated by observers, right) for SCI 2.

The fit to the length frequency distributions derived from photographic surveys was variable (Figure 71), but may be as good as could be expected given the uncertainties in their derivation. The general form of the fits to the research trawl length frequency data were reasonable (Figure 72 to Figure 74), although as with the SCI 1 model, the variability observed between years was not matched by the model, and neither was the observed variation in sex ratio (Figure 70). The fits to the commercial length frequency data were poor (Figure 75 & Figure 78).

Likelihood profiling of the base model (by fixing key parameters at a range of values and refitting the model at each level) suggested that a wide range of biomass levels produced similar likelihoods (the overall profile was relatively flat, Figure 79), but only a relatively narrow range of M was tolerated (the overall profile was relatively steep, Figure 80). Note the scales are different in the plots. Additions to the likelihood components for each term are provided in Table 23. The likelihood profile for B_0 responded strongly at the lowest levels of stock size, but otherwise most levels were equally likely. Excluding this lowest B_0 level, overall the proportion at length data (particularly the step 2 research trawl data) were most influential, although the prior on q-Photo also had influence at B_0 levels > 10 000 t.

The likelihood profile for M was most strongly affected by the research proportion at length and both research and commercial trawl selectivity data sets (though in conflicting directions) and to a far lesser extent by the prior for recruitment YCS, and the photo survey relative abundance index. There was some evidence that the trawl survey proportion at length data from different time steps provided conflicting information. The research trawl selectivity data and prior for recruitment YCS favoured smaller values of M, while the proportion at length from the research trawl survey (time step 2) and commercial trawl selectivity data favoured larger values of M.

The base (N) model produced very similar estimates of B_0 and B_{2005} than the base (B) model (photo survey as biomass), and the trends over time and 2005 biomass as a proportion of B_0 were almost identical. The base (N) model was not sensitive to the inclusion of all the observer data, excluding the CPUE and trawl survey indices, relaxing the prior on M, the constraint on YCS to fit a 3[rd] order polynomial, or varying the estimates for 2006 landings (Table 24). However, it was sensitive to the flexibility to fit process error relative to the abundance indices, excluding the cod end selectivity data, applying a different prior on q-Photo, and the amount of constraint put on the recruitment variability. Allowing the model to fit process error for the abundance indices resulted in lower estimates of process error than specified in the base model, and lower estimates of B_0 and B_{2005} relative to B_0, for both the Base (N) and Base (B) models. Excluding the cod end data from the model resulted in higher

L_{50} values for both trawl data sets, and lower estimates of B_0 and B_{2005} relative to B_0. Applying the prior for q-Photo based on approach 1 (uniform distributions of occupancy and detection, resulting in a prior with high cv) resulted in an estimate of q-Photo of 4.21 (compared to 2.46 in the base model), with an associated reduction in the estimate of B_0. Applying the prior for q-Photo based on approach 2 produced similar output to the base model. Increasing the constraint put on recruitment variability (reducing YCS cv to 0.1) increased the estimate of B_0, with and without YCS constrained to fit a 3rd order polynomial.

None of the estimates of B_0 seem implausible, ranging from 2 016 to 4 378 tonnes. M appeared relatively insensitive to the modelling choices (consistently 0.22 - 0.25), which may be an artefact of the imposed growth model and observed length frequency distributions (Cryer at al. 2005), and is in the region of anticipated values. The estimates of q-Photo were consistently > 1.0, and generally > 2.0, which is higher than estimated in any of the SCI 1 runs, or was anticipated. B_{2005} was generally estimated to be 40 - 55% of B_0, although the run with the highest estimate of q-Photo had an estimate of 35%, and the two runs with most constraint on YCS had estimates to about 75% of B_0.

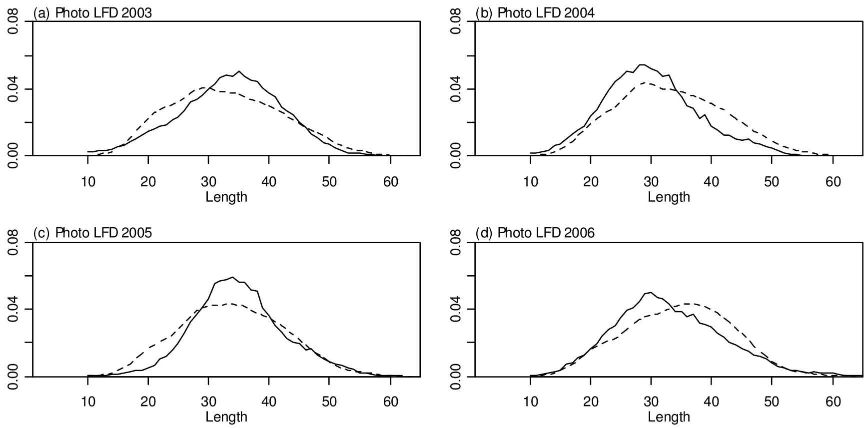

Figure 71: Observed (solid lines) and fitted (dashed lines) length frequency distributions from photographic surveys for SCI 2.

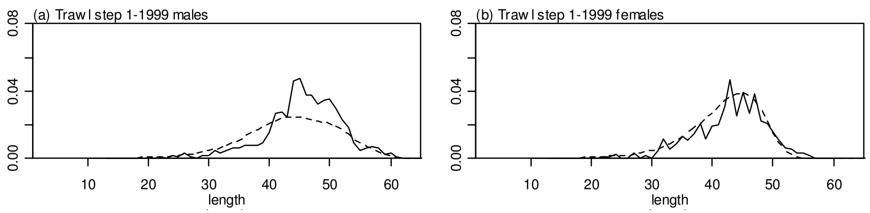

Figure 72: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 trawl surveys for SCI 2.

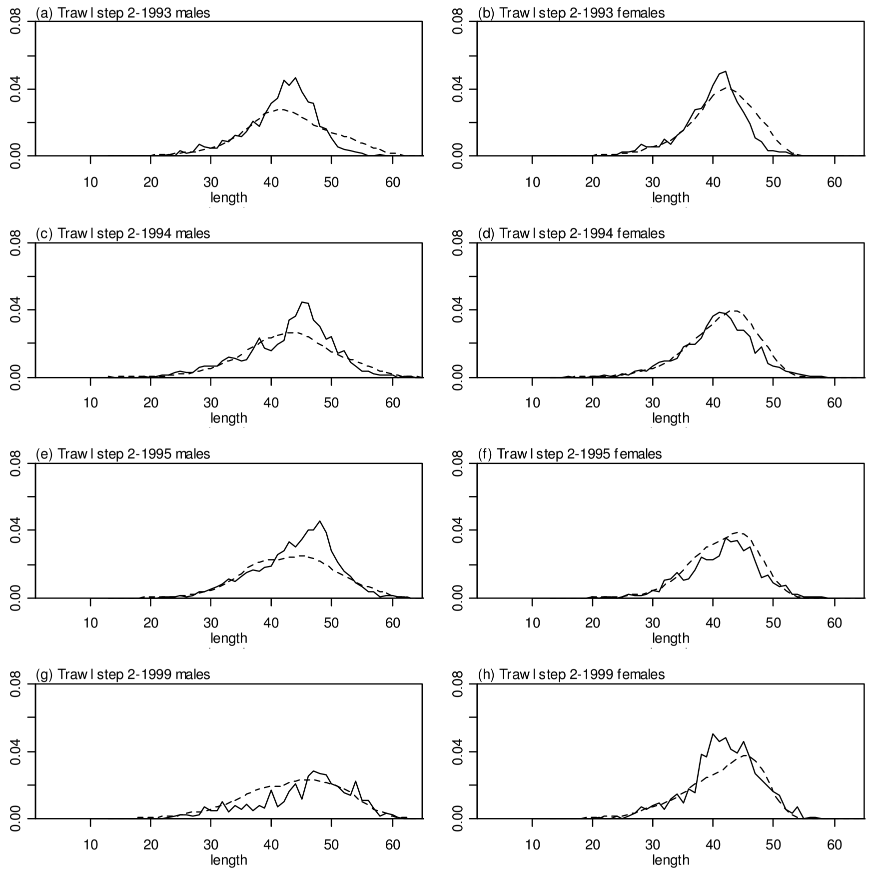

Figure 73: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys (1993-1999) for SCI 2.

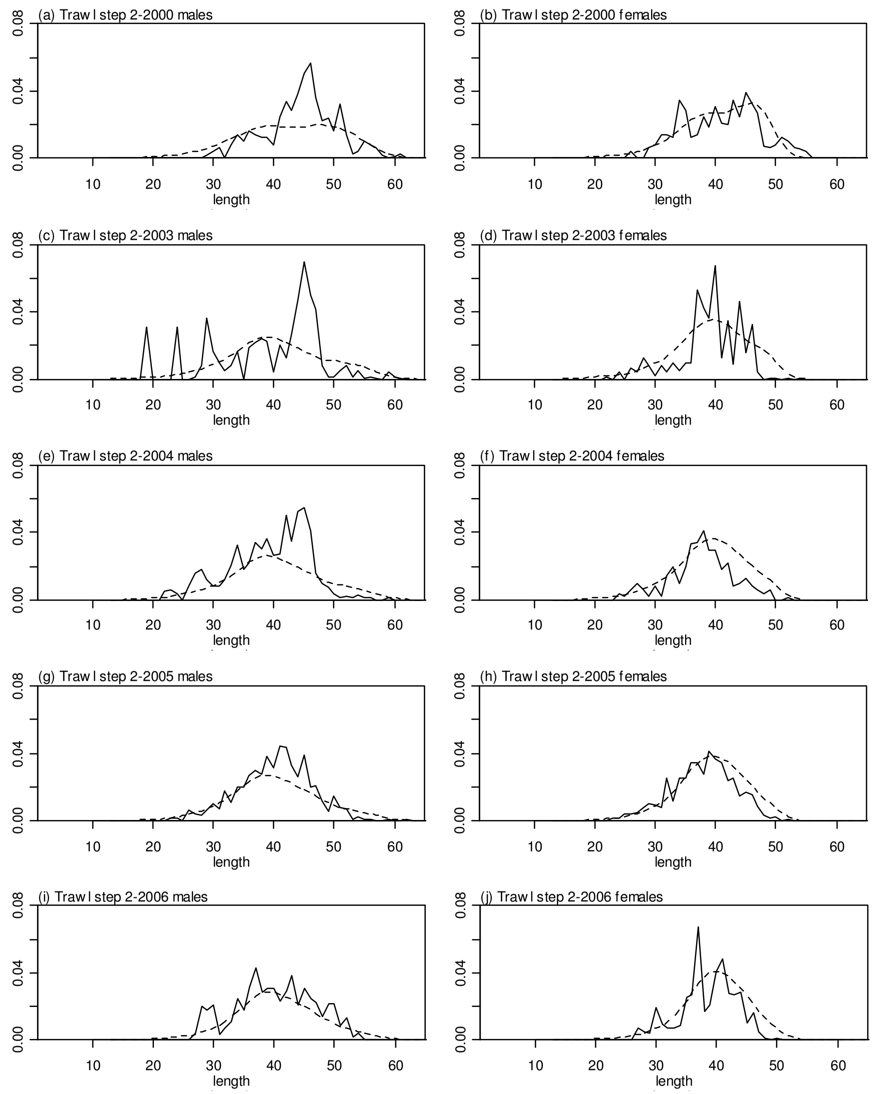

Figure 74: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 trawl surveys (2000-2006) for SCI 2.

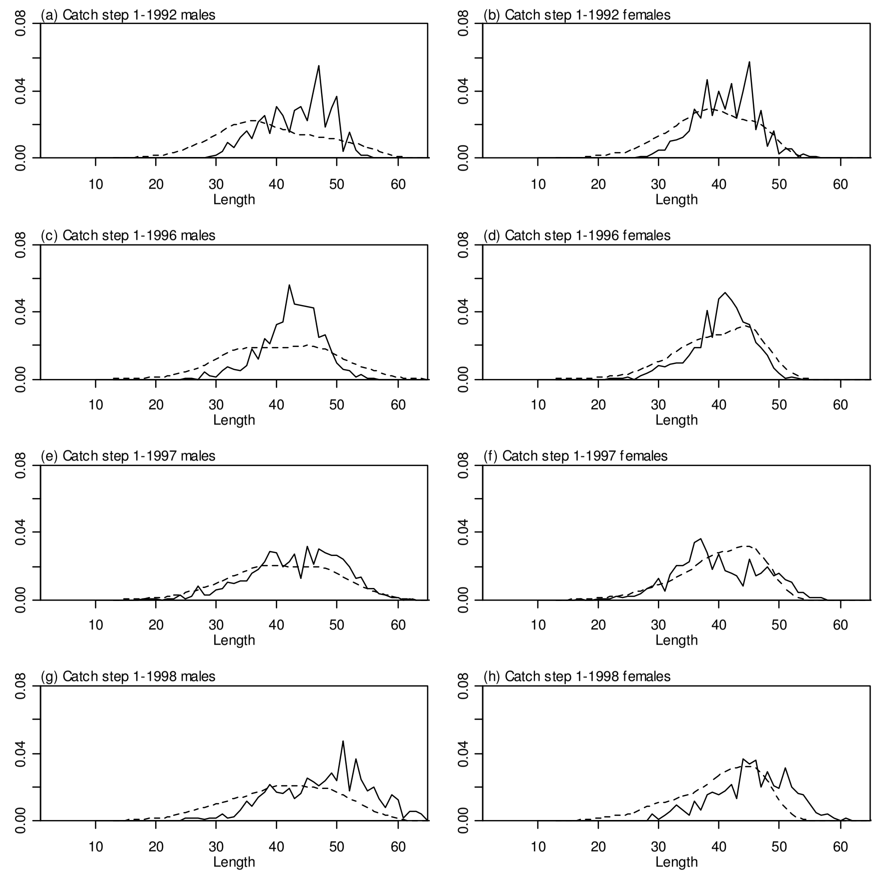

Figure 75: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 commercial catch (1992-1998) for SCI 2.

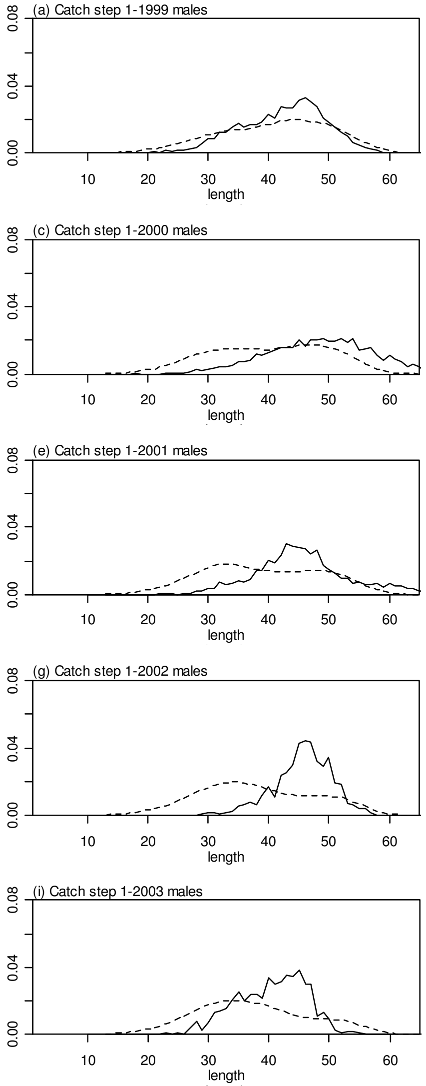

Figure 76: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 1 commercial catch (1999-2003) for SCI 2.

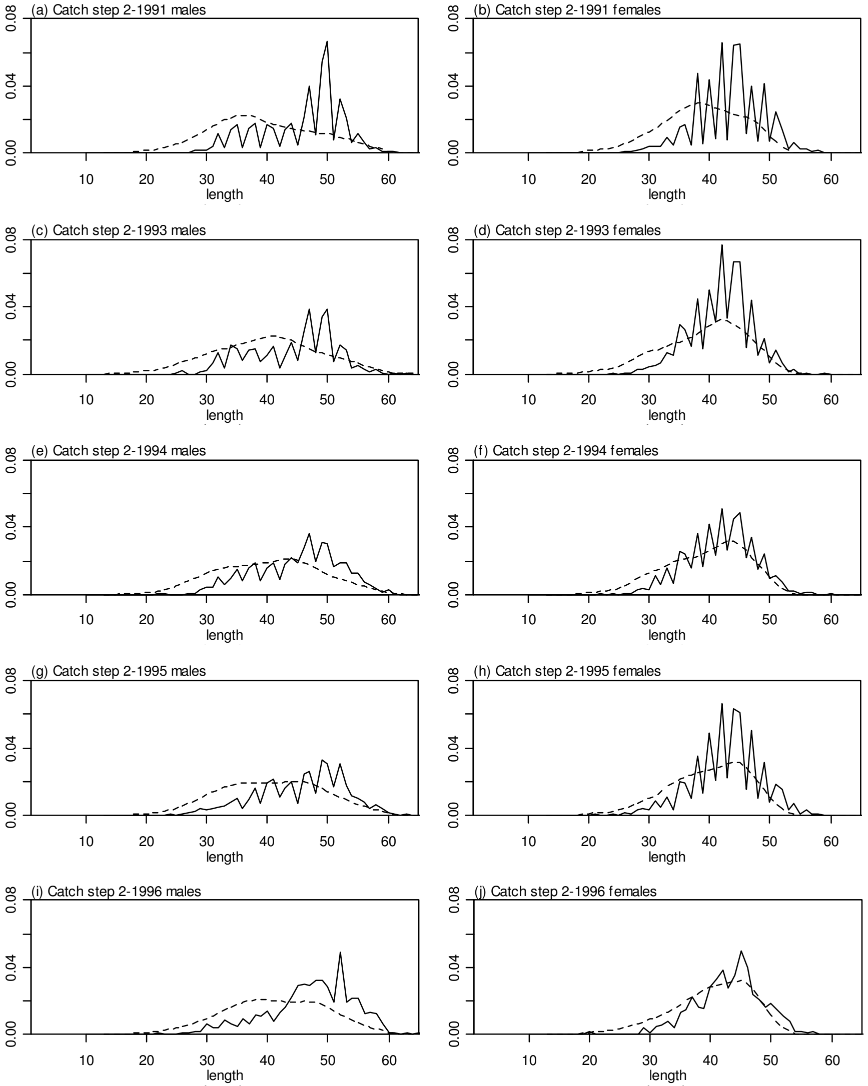

Figure 77: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 commercial catch (1991-1996) for SCI 2.

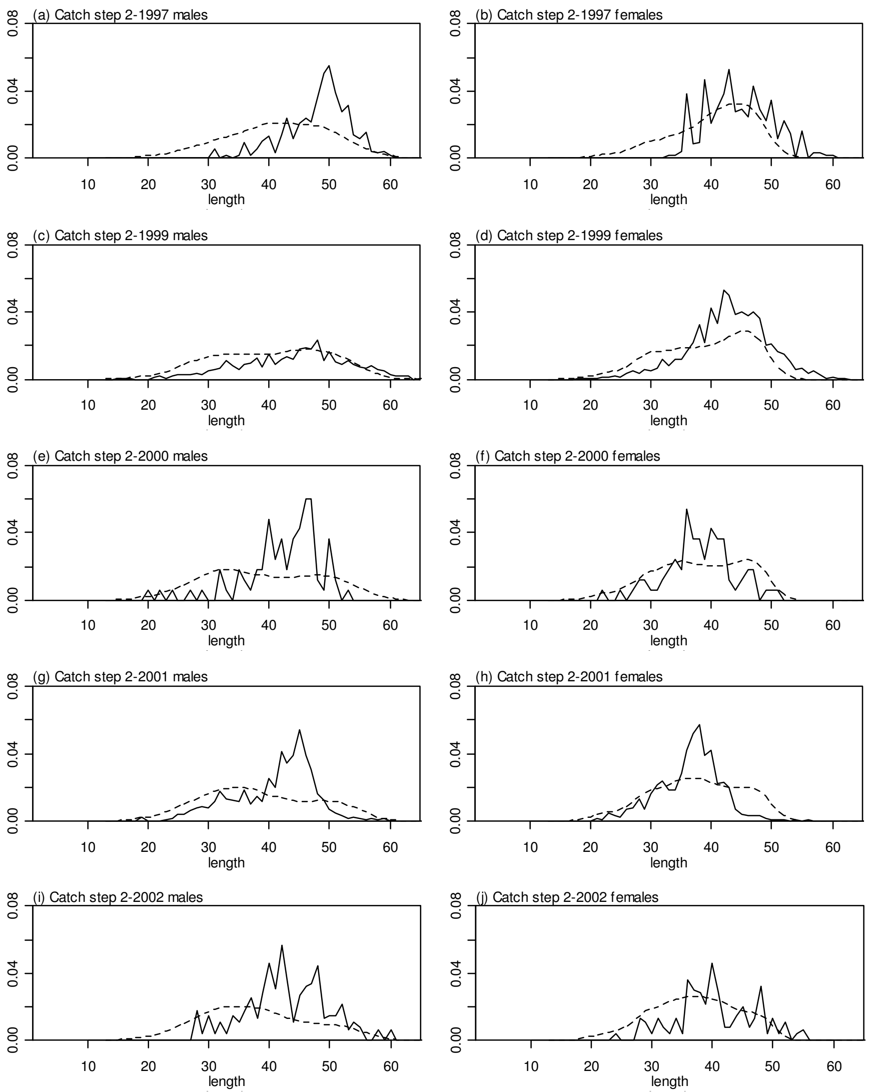

Figure 78: Observed (solid lines) and fitted (dashed lines) length frequency distributions from time step 2 commercial catch (1997-2002) for SCI 2.

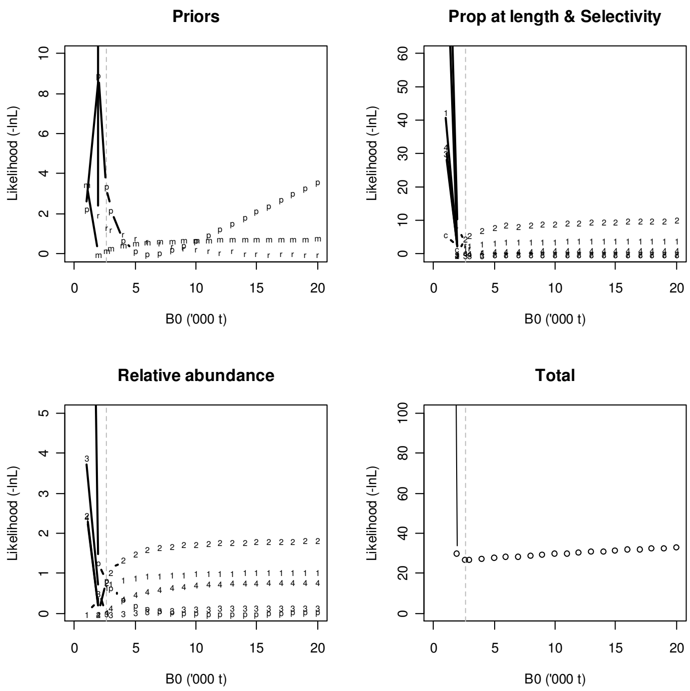

Figure 79: Likelihood profiles for the base model when B_0 is fixed in the model for SCI 2. Figures show profiles for main priors (top left: p – qPhoto, r – recruitment YCS, m – natural mortality), proportion at length data (top right: 1 – trawl survey step 1, 2 – trawl survey step 2, 3 – comm observer step 1, 4 – comm observer step 2, c – selectivity of commercial trawl, r – selectivity of research trawl), relative abundance data (bottom left: j – CPUE step 1, o – CPUE step 2, p – photo survey, t – trawl survey) individually, and for the whole model (bottom right).

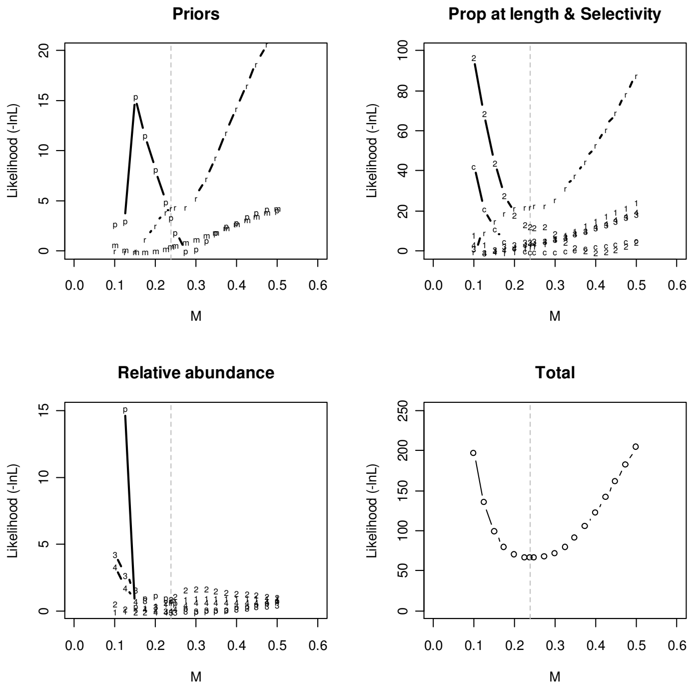

Figure 80: Likelihood profiles for the base model (N process error fitted externally) when M is fixed in the model for SCI 2. Figures show profiles for main priors (top left: p – qPhoto, r – recruitment YCS, m – natural mortality), proportion at length data (top right: 1 – trawl survey step 1, 2 – trawl survey step 2, 3 – comm observer step 1, 4 – comm observer step 2, c – selectivity of commercial trawl, r – selectivity of research trawl), relative abundance data (bottom left: j – CPUE step 1, o – CPUE step 2, p – photo survey, t – trawl survey) individually, and for the whole model (bottom right).

Table 23: Additions to likelihood components (over and above the minimum for each) for the base model (Base (N)) for each data set and for the priors and penalties when B_0 or M are fixed at values between 1 000 and 20 000 t and 0.1 and 0.5, respectively for SCI 2. The MPD fit for the base model is in bold font.

	relative abundance					proportion at length								prior											penalty		
B_0	CPUE-Commercial-Jan	CPUE-Commercial-Oct	PhotoSurvey	TrawlSurvey-Jan	TrawlSurvey-Oct	Photo-Jan	Trawl-Jan	Trawl-Oct	Commercial-Jan	Commercial-Oct	Cryer_Oliver_maturity	SHSP05_expt_comm	SHSP05_expt_rsch	initialization.B0	natural_mortality.all	PhotoSurvey.cv_process_error	recruitment.YCS	prior_on_maturity_props.all	selectivity[FishingSel].male	selectivity[TrawlSurveySel].male	selectivity[PhotoSurveySel].male	q_CPUE	q_Photo	q_Trawl	OctCatchMustBeTaken	JanCatchMustBeTaken	YCS_average_1
1.000	2.4	3.9	22.3	2.5	0.0	41.9	102.4	42.9	32.4	30.5	11.7	6.0	150.7	0.0	3.5	0.0	383.5	0.0	0.0	0.0	0.0	3.6	2.3	5.1	0.0	0.0	18.8
2.000	0.0	0.5	1.3	0.0	0.4	0.0	0.0	0.0	0.0	0.2	0.0	1.6	7.9	0.7	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.9	8.9	3.2	0.0	0.0	0.0
2.644	**0.0**	**0.0**	**0.8**	**0.8**	**0.7**	**2.3**	**4.8**	**2.0**	**0.4**	**0.0**	**0.0**	**0.5**	**2.9**	**1.0**	**0.2**	**0.0**	**1.4**	**0.0**	**0.0**	**0.0**	**0.0**	**2.4**	**3.4**	**2.5**	**0.0**	**0.0**	**0.0**
3.000	0.2	0.0	0.6	1.0	0.8	3.0	5.8	2.6	0.6	0.0	0.0	0.4	2.1	1.1	0.3	0.0	1.3	0.0	0.0	0.0	0.0	2.2	2.2	2.3	0.0	0.0	0.0
4.000	0.4	0.0	0.4	1.4	0.9	3.9	7.5	3.4	0.9	0.0	0.0	0.2	0.9	1.4	0.5	0.0	1.1	0.0	0.0	0.0	0.0	1.8	0.7	1.8	0.0	0.0	0.0
5.000	0.5	0.1	0.2	1.5	0.9	4.3	8.3	3.8	1.0	0.1	0.0	0.1	0.5	1.6	0.6	0.0	0.9	0.0	0.0	0.0	0.0	1.5	0.1	1.6	0.0	0.0	0.0
6.000	0.6	0.1	0.1	1.6	1.0	4.6	8.9	4.0	1.1	0.1	0.0	0.0	0.2	1.8	0.6	0.0	0.7	0.0	0.0	0.0	0.0	1.3	0.0	1.3	0.0	0.0	0.0
7.000	0.6	0.1	0.1	1.7	1.0	4.5	8.7	3.9	1.2	0.1	0.0	0.1	0.7	1.9	0.7	0.0	0.6	0.0	0.0	0.0	0.0	1.1	0.1	1.1	0.0	0.0	0.0
8.000	0.7	0.1	0.1	1.7	1.0	4.6	9.0	4.0	1.3	0.1	0.0	0.1	0.6	2.1	0.7	0.0	0.4	0.0	0.0	0.0	0.0	1.0	0.2	1.0	0.0	0.0	0.0
9.000	0.7	0.1	0.0	1.7	1.0	4.7	9.2	4.0	1.3	0.2	0.0	0.0	0.5	2.2	0.7	0.0	0.3	0.0	0.0	0.0	0.0	0.9	0.4	0.9	0.0	0.0	0.0
10.000	0.7	0.1	0.0	1.8	1.0	4.7	9.4	4.1	1.3	0.1	0.0	0.0	0.5	2.3	0.7	0.0	0.3	0.0	0.0	0.0	0.0	0.7	0.7	0.7	0.0	0.0	0.0
11.000	0.7	0.1	0.0	1.8	1.0	4.8	9.6	4.1	1.3	0.1	0.0	0.0	0.4	2.4	0.8	0.0	0.2	0.0	0.0	0.0	0.0	0.6	1.0	0.6	0.0	0.0	0.0
12.000	0.8	0.1	0.0	1.8	1.0	4.9	9.7	4.1	1.4	0.1	0.0	0.0	0.4	2.5	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.5	1.2	0.5	0.0	0.0	0.0
13.000	0.8	0.2	0.0	1.8	1.0	4.9	9.8	4.2	1.4	0.1	0.0	0.0	0.3	2.6	0.8	0.0	0.2	0.0	0.0	0.0	0.0	0.5	1.5	0.5	0.0	0.0	0.0
14.000	0.8	0.2	0.0	1.8	1.0	4.9	9.9	4.2	1.4	0.1	0.0	0.0	0.3	2.6	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.4	1.8	0.4	0.0	0.0	0.0
15.000	0.8	0.2	0.0	1.8	1.0	5.0	10.0	4.3	1.4	0.1	0.0	0.0	0.2	2.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.1	0.3	0.0	0.0	0.0
16.000	0.8	0.2	0.0	1.8	1.0	5.0	10.1	4.3	1.4	0.1	0.0	0.0	0.2	2.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.4	0.2	0.0	0.0	0.0
17.000	0.8	0.2	0.0	1.8	1.0	5.0	10.2	4.3	1.4	0.1	0.0	0.0	0.1	2.8	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.2	2.7	0.2	0.0	0.0	0.0
18.000	0.8	0.2	0.0	1.8	1.0	5.0	10.3	4.3	1.4	0.1	0.0	0.0	0.0	2.9	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.1	3.0	0.1	0.0	0.0	0.0
19.000	0.8	0.2	0.0	1.8	1.0	5.1	10.3	4.3	1.4	0.1	0.0	0.0	0.0	2.9	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.3	0.1	0.0	0.0	0.0
20.000	0.8	0.2	0.0	1.9	1.1	5.1	10.4	4.3	1.4	0.1	0.0	0.0	0.0	3.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0
M																											
0.100	3.4	4.3	16.9	0.7	0.0	6.2	97.5	8.6	3.9	1.8	0.0	42.9	0.0	0.1	0.7	0.0	0.1	0.0	0.0	0.0	0.0	3.5	2.7	3.3	0.0	0.0	0.0
0.125	1.8	2.8	15.2	0.3	0.1	1.1	69.2	3.8	0.0	0.0	0.0	21.5	9.7	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	3.4	3.0	3.2	0.0	0.0	0.0
0.150	0.8	1.6	0.3	0.0	0.2	0.9	44.4	0.9	0.1	1.1	0.0	11.5	15.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	3.3	15.4	3.1	0.0	0.0	0.0
0.175	0.2	0.9	1.0	0.0	0.3	0.9	28.3	0.0	1.3	2.7	0.0	5.4	19.3	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	3.1	11.6	2.9	0.0	0.0	0.0
0.200	0.0	0.4	1.1	0.3	0.4	1.0	18.5	0.3	2.6	4.0	0.0	2.2	22.2	0.0	0.2	0.0	2.6	0.0	0.0	0.0	0.0	2.9	8.1	2.7	0.0	0.0	0.0
0.225	0.0	0.1	1.0	0.7	0.6	1.9	13.8	1.9	3.8	4.8	0.0	0.7	22.7	0.1	0.4	0.0	4.0	0.0	0.0	0.0	0.0	2.6	4.9	2.4	0.0	0.0	0.0
0.238	**0.1**	**0.0**	**0.8**	**1.0**	**0.7**	**2.4**	**13.0**	**2.8**	**4.3**	**5.2**	**0.0**	**0.3**	**22.7**	**0.3**	**0.5**	**0.0**	**4.4**	**0.0**	**0.0**	**0.0**	**0.0**	**2.4**	**3.3**	**2.1**	**0.0**	**0.0**	**0.0**
0.250	0.3	0.0	0.6	1.2	0.8	2.7	12.5	3.2	4.7	5.4	0.0	0.2	23.1	0.4	0.7	0.0	4.5	0.0	0.0	0.0	0.0	2.2	1.9	1.9	0.0	0.0	0.0
0.275	0.6	0.1	0.2	1.6	1.0	3.4	12.7	4.7	5.4	5.8	0.0	0.0	23.0	0.9	1.0	0.0	4.5	0.0	0.0	0.0	0.0	1.6	0.0	1.2	0.0	0.0	0.0
0.300	0.7	0.1	0.0	1.8	1.0	2.6	9.4	6.5	6.4	6.6	0.0	0.2	26.1	1.4	1.3	0.0	5.4	0.0	0.0	0.0	0.0	1.0	0.2	0.6	0.0	0.0	0.0
0.325	0.7	0.1	0.0	1.7	1.0	1.4	5.1	8.6	7.8	7.8	0.0	0.7	31.7	1.7	1.7	0.0	7.3	0.0	0.0	0.0	0.0	0.6	1.1	0.3	0.0	0.0	0.0
0.350	0.7	0.2	0.1	1.6	1.0	0.5	2.2	10.9	9.3	9.2	0.0	1.3	38.2	1.9	2.0	0.0	9.4	0.0	0.0	0.0	0.0	0.5	1.9	0.2	0.0	0.0	0.0
0.375	0.7	0.2	0.2	1.5	1.0	0.0	0.6	13.3	10.9	10.8	0.0	1.9	45.1	2.0	2.4	0.0	11.9	0.0	0.0	0.0	0.0	0.3	2.6	0.1	0.0	0.0	0.0
0.400	0.7	0.3	0.3	1.4	1.0	0.0	0.0	15.7	12.7	12.4	0.0	2.6	53.1	2.0	2.8	0.0	14.3	0.0	0.0	0.0	0.0	0.3	2.9	0.1	0.0	0.0	0.0
0.425	0.7	0.3	0.4	1.3	1.0	0.4	0.5	18.0	14.5	14.0	0.0	3.4	61.2	2.1	3.2	0.0	16.6	0.0	0.0	0.0	0.0	0.2	3.4	0.0	0.0	0.0	0.0
0.450	0.7	0.4	0.5	1.2	1.0	1.1	1.5	20.3	16.3	15.6	0.0	4.2	69.7	2.2	3.6	0.0	18.8	0.0	0.0	0.0	0.0	0.1	3.9	0.0	0.0	0.0	0.0
0.475	0.8	0.5	0.6	1.2	1.0	2.1	3.1	22.5	18.2	17.3	0.0	5.1	78.6	2.3	4.0	0.0	20.7	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0
0.500	0.9	0.6	0.7	1.1	1.0	3.3	4.9	24.6	20.2	19.1	0.0	6.0	88.0	2.3	4.4	0.0	22.4	0.0	0.0	0.0	0.0	0.0	4.0	0.1	0.0	0.0	0.0

Table 24: Estimated parameters and quantities from the base case and sensitivity MPD fits for the SCI 2 modelled area.

Estimated parameters	Base (B)	Base (B, PE)	Base (N)	Base (N, PE)	All_obs	NoCPUE	NoCPUE/TRAWL	NoCodEnd	q-Photo 1
initialization.B0	2582	2332	2644	2335	2735	2547	2641	2016	2182
natural_mortality.all	0.236	0.226	0.238	0.226	0.236	0.236	0.238	0.250	0.220
PhotoSurvey.cv_process_error	0.126	0.129	0.126	0.138	0.121	0.127	0.124	0.147	0.140
CPUE-Commercialq	0.0207	0.0184	0.0199	0.0185	0.0191			0.0367	0.0285
PhotoSurveyq	2.3297	3.0625	2.4616	3.3677	2.3350	2.6333	2.4469	3.2742	4.2187
TrawlSurveyq	0.0015	0.0014	0.0014	0.0014	0.0013	0.0015		0.0029	0.0022
R0	2.20E+07	1.82E+07	2.28E+07	1.82E+07	2.33E+07	2.16E+07	2.27E+07	1.92E+07	1.61E+07
YCS_1986	1.29	1.27	1.28	1.27	1.29	1.28	1.28	1.23	1.27
YCS_1987	1.82	1.85	1.81	1.85	1.80	1.80	1.78	1.68	1.84
YCS_1988	1.55	1.63	1.53	1.60	1.53	1.53	1.51	1.59	1.60
YCS_1989	1.16	1.21	1.14	1.20	1.15	1.15	1.13	1.24	1.20
YCS_1990	1.04	1.10	1.04	1.09	1.03	1.04	1.03	1.14	1.09
YCS_1991	1.11	1.18	1.11	1.19	1.10	1.11	1.11	1.20	1.18
YCS_1992	1.02	1.07	1.02	1.07	1.01	1.02	1.01	1.01	1.07
YCS_1993	0.68	0.69	0.67	0.68	0.68	0.67	0.67	0.66	0.69
YCS_1994	0.55	0.55	0.54	0.55	0.54	0.54	0.54	0.55	0.56
YCS_1995	0.57	0.57	0.57	0.58	0.56	0.57	0.57	0.58	0.58
YCS_1996	0.59	0.58	0.59	0.58	0.58	0.59	0.59	0.60	0.59
YCS_1997	0.79	0.77	0.79	0.77	0.79	0.79	0.80	0.80	0.79
YCS_1998	0.78	0.75	0.78	0.74	0.79	0.79	0.79	0.74	0.77
YCS_1999	0.88	0.83	0.88	0.82	0.90	0.89	0.90	0.80	0.85
YCS_2000	0.96	0.89	0.98	0.90	0.98	0.97	0.99	0.90	0.89
YCS_2001	1.01	0.93	1.03	0.95	1.04	1.02	1.05	1.01	0.93
YCS_2002	1.21	1.12	1.24	1.14	1.24	1.23	1.25	1.28	1.12
YCS_2003	1.11	1.06	1.13	1.08	1.13	1.12	1.15	1.17	1.05
YCS_2004	0.99	0.96	0.97	0.94	0.98	0.97	0.98	1.00	0.94
YCS_2005	0.98	0.97	0.96	0.94	0.96	0.96	0.95	0.98	0.95
Maturity50	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18	30.18
MaturityTo95	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34
Comm50	28.91	29.13	28.88	29.14	29.31	28.91	28.88	36.73	29.08
CommTo95	10.35	10.71	10.32	10.62	10.26	10.30	10.29	6.89	10.68
CommAsy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.71	1.00
Rsch50	34.78	34.81	34.91	34.97	34.62	34.89	34.95	39.46	35.02
RschTo95	6.20	6.09	5.43	5.28	6.20	5.99	5.43	12.31	6.09
RschAsy	2.63	2.76	3.47	3.73	2.62	2.84	3.47	1.00	2.77
Photo50	21.84	21.97	21.43	21.54	21.30	21.66	21.40	22.56	21.97
PhotoTo95	7.24	7.32	7.84	7.85	7.28	6.43	7.96	6.43	7.45
PhotoAsy	5.30	5.22	4.28	4.35	5.60	9.58	4.25	9.37	5.28
B2005	1274	952	1353	958	1445	1245	1360	883	774
B2005/B1985	0.49	0.41	0.51	0.41	0.53	0.49	0.52	0.44	0.35

Estimated parameters	q-Photo 2	FreeM	cvYCS10%	cvYCS40%	YCS smoothing	YCS smooth & cv10%	YCS smooth & cv40%	2006 zero landings	2006 double 2005 landings
initialization.B0	2757	2769	4188	2450	2741	4378	2732	2689	2613
natural_mortality.all	0.241	0.243	0.254	0.244	0.241	0.255	0.253	0.240	0.237
PhotoSurvey.cv_process_error	0.120	0.120	0.084	0.129	0.126	0.087	0.121	0.127	0.121
CPUE-Commercialq	0.0186	0.0184	0.0104	0.0220	0.0188	0.0098	0.0183	0.0194	0.0203
PhotoSurveyq	2.2401	2.2219	1.1602	3.0457	2.2669	1.0906	2.3868	2.3603	2.5135
TrawlSurveyq	0.0013	0.0013	0.0007	0.0016	0.0013	0.0007	0.0013	0.0014	0.0015
R0	2.45E+07	2.49E+07	4.13E+07	2.23E+07	2.42E+07	4.37E+07	2.68E+07	2.36E+07	2.25E+07
YCS_1986	1.28	1.29	1.13	1.11	1.53	1.16	2.16	1.28	1.28
YCS_1987	1.79	1.80	1.23	3.23	1.50	1.20	1.79	1.80	1.80
YCS_1988	1.52	1.53	1.22	1.34	1.42	1.19	1.53	1.53	1.54
YCS_1989	1.14	1.14	1.10	1.12	1.30	1.14	1.33	1.15	1.15
YCS_1990	1.03	1.03	1.03	1.03	1.17	1.08	1.17	1.03	1.04
YCS_1991	1.10	1.10	1.03	1.13	1.03	1.01	1.01	1.10	1.11
YCS_1992	1.01	1.01	0.98	1.12	0.87	0.93	0.82	1.01	1.02
YCS_1993	0.67	0.67	0.83	0.53	0.71	0.84	0.63	0.67	0.68
YCS_1994	0.54	0.54	0.74	0.40	0.60	0.77	0.49	0.54	0.54
YCS_1995	0.57	0.56	0.75	0.49	0.56	0.75	0.44	0.56	0.57
YCS_1996	0.59	0.58	0.78	0.43	0.61	0.79	0.49	0.58	0.59
YCS_1997	0.79	0.79	0.89	0.75	0.70	0.85	0.60	0.79	0.79
YCS_1998	0.79	0.79	0.91	0.65	0.81	0.93	0.72	0.79	0.78
YCS_1999	0.90	0.90	0.98	0.81	0.92	1.00	0.83	0.89	0.89
YCS_2000	0.99	0.98	1.05	0.86	1.02	1.08	0.92	0.98	0.97
YCS_2001	1.04	1.04	1.12	0.87	1.10	1.13	1.01	1.04	1.03
YCS_2002	1.26	1.26	1.21	1.13	1.15	1.15	1.07	1.25	1.23
YCS_2003	1.14	1.13	1.10	1.03	1.13	1.11	1.02	1.13	1.12
YCS_2004	0.97	0.98	1.00	0.86	1.06	1.05	0.97	0.98	0.97
YCS_2005	0.96	0.96	0.98	0.87	0.92	0.96	0.83	0.96	0.95
Maturity50	30.18	30.18	30.17	30.18	30.18	30.18	30.18	30.18	30.18
MaturityTo95	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34
Comm50	28.88	28.84	28.51	29.29	28.88	28.52	29.11	28.90	28.92
CommTo95	10.25	10.30	10.01	10.72	10.26	9.99	10.33	10.29	10.37
CommAsy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rsch50	34.79	34.79	34.95	34.59	34.80	34.91	34.45	34.79	34.82
RschTo95	6.01	6.26	6.40	4.88	6.54	6.63	6.10	6.25	6.22
RschAsy	2.80	2.57	2.60	4.05	2.46	2.46	2.69	2.59	2.62
Photo50	21.55	21.52	20.57	21.91	21.27	20.42	21.83	21.52	21.49
PhotoTo95	6.47	7.18	7.36	7.82	7.68	7.46	6.73	7.17	7.34
PhotoAsy	10.00	5.67	5.26	4.25	5.09	5.35	10.00	5.52	5.51
B2005	1486	1503	3140	1041	1471	3344	1342	1413	1315
B2005/B1985	0.54	0.54	0.75	0.42	0.54	0.76	0.49	0.53	0.50

4 DISCUSSION

4.1 State of scampi stocks

The models developed within this project are presented as "work in progress", with the model for SCI 2 in particular, a "first cut" to length based assessment for this stock. The stock in SCI 1 between the Mercury Islands and White Island, 300-500 m depth, was selected for initial model development (Cryer et al., 2005) because it has been fished for the longest, and substantially more information was available from a variety of sources (particularly photographic surveys) when the model was first being developed. Since this initial work, a series of photographic surveys for SCI 2 have been conducted, and a model for SCI 2 has been developed. Model outputs in relation to the state of the stocks are presented below, but the preliminary nature of the model development should be borne in mind in considering these findings.

SCI 1

Data in the model provided inconsistent signals about stock size and mortality, and the outputs were therefore sensitive to the relative weighting given to the data (particularly the proportion at length data). The base model for SCI 1 (with process error fitted externally) suggests that B_0 for scampi between the Mercury Islands and White Island, 300-500 m depth, is about 5 300 t, although this estimate is sensitive to model assumptions, and a range of B_0 from 3 034 to 5 619 t seems plausible. B_{2005} was consistently estimated to be 67 - 71% of B_0. Within this set of models, M was consistently estimated at about 0.38, which is considered high given our knowledge of scampi growth, and hence longevity.

Fitting a base model with process error set equally for research proportion at length and commercial catch at length data suggested that B_0 is higher, at about 7 100 t, although this estimate was also sensitive to model assumptions, and a range of B_0 from 4 300 to 8 400 t seems plausible. Within this set of models, M was consistently estimated at about 0.24, which is consistent with knowledge of scampi growth, and B_{2005} was consistently estimated to be 74 - 89% of B_0.

Both sets of models appeared to be constrained in their choices of values for M, which may be an artefact of the imposed growth model. Neither of the models fitted the cyclical pattern observed in the CPUE or trawl survey index well, or the variability in sex ratio in research and commercial catches observed between years. Fits to the commercial catch at length data were also poor. While the base models are clearly sensitive to the relative data weighting, B_{2005} was consistently estimated to be 70 - 90% of B_0.

SCI 2

The base model for SCI 2 (with process error fitted externally) suggests that B_0 for scampi between the Mahia Peninsular and Castle Point, 300-500 m depth, is about 2 600 t, although this estimate is sensitive to model assumptions, and a range of B_0 from 2 000 to 4 400 t seems plausible. B_{2005} was generally estimated to be 40 - 55% of B_0, although the range from all runs extended from 35% to 75%. Within this set of models, M was consistently estimated to be between 0.22 and 0.25.

As with SCI 1, the SCI 2 models appeared to be constrained in their choices of values for M. The cyclical pattern observed in the CPUE data was not fitted well by the model, nor was the variability in sex ratio in research and commercial catches observed between years. The SCI 2 stock appears to be in a more heavily exploited state than the stock in the SCI 1 modelled area (B_{2005} estimated to be a lower proportion of B_0), although q-Photo was estimated to be far higher in SCI 2, which would have a negative influence on the estimate of stock size.

4.2 Future model developments

The models for both stocks provided evidence that within the structure of the base model, the proportion and catch at length data from the two time steps were providing conflicting information about the size of the stock. This was interpreted as the possible influence of seasonal patterns in burrow emergence leading to different availability of the stock to the fishery between time steps (and possibly sex), and investigated further for SCI 1. Allowing selectivity to vary improved the fits to the proportion and catch at length data, but the generally poor fit to the variability in sex ratio observed between years and the CPUE data, suggested that further work should investigate whether the current time steps used in the model are the most appropriate. Objective 3 of the current MFish project SCI 2006/01 will investigate patterns in size and sex distribution of scampi from research and observer data, and will help identify seasonal patterns to inform model time step selection.

In the current model structure, observed proportions and catches at length are related to the stock partition through the trawl selectivity parameters, and has been fitted to cod end selectivity is most instances. This may not be totally appropriate, since scampi availability to trawl gear is a function of burrow emergence and whole gear selectivity, and other approaches, particularly in relation to ogive shape, could be investigated. Work to investigate scampi emergence was recently proposed at the Shellfish Research Planning meeting.

The development of the SCI 1 model also investigated applying a different growth approach within the model, which also appeared to improve the fits. For the SCI 2 model, the SCI 1 approach of modelling the stock within the photo survey area was adopted as a starting point, but investigation of the length data suggested that some spatial stratification may be appropriate, and the SCI 2006/01 study will also help inform this process.

A number of parameters would be expected to be similar between areas (M, growth, trawl selectivity, q-Photo) and the trends estimated in recruitment were similar (possibly suggesting similar drivers are affecting recruitment in the two areas). The development of a multi stock model where certain parameters are estimated across all areas (or at least limited to be within certain bounds of each other between areas) may improve the model, and should also be investigated.

A number of suggestions for future investigations are listed below. These potential directions for development are not independent, and best progress may be made by examining related aspects (eg availability, time steps and stratification) simultaneously.

- Further investigations into seasonal and sex related variability in scampi availability (at length) to the fishery.

- Investigate spatial stratification of SCI 2, and alternative time steps within the model.

- Consideration of means of including photographic estimates of minimum absolute recruited biomass in the model.

- Fitting growth parameters within the model.

- Fitting to a tag-based estimate of absolute abundance within the model (using 1995 tag data for SCI 1).

- Multi-stock model with certain parameters estimated across all stocks.

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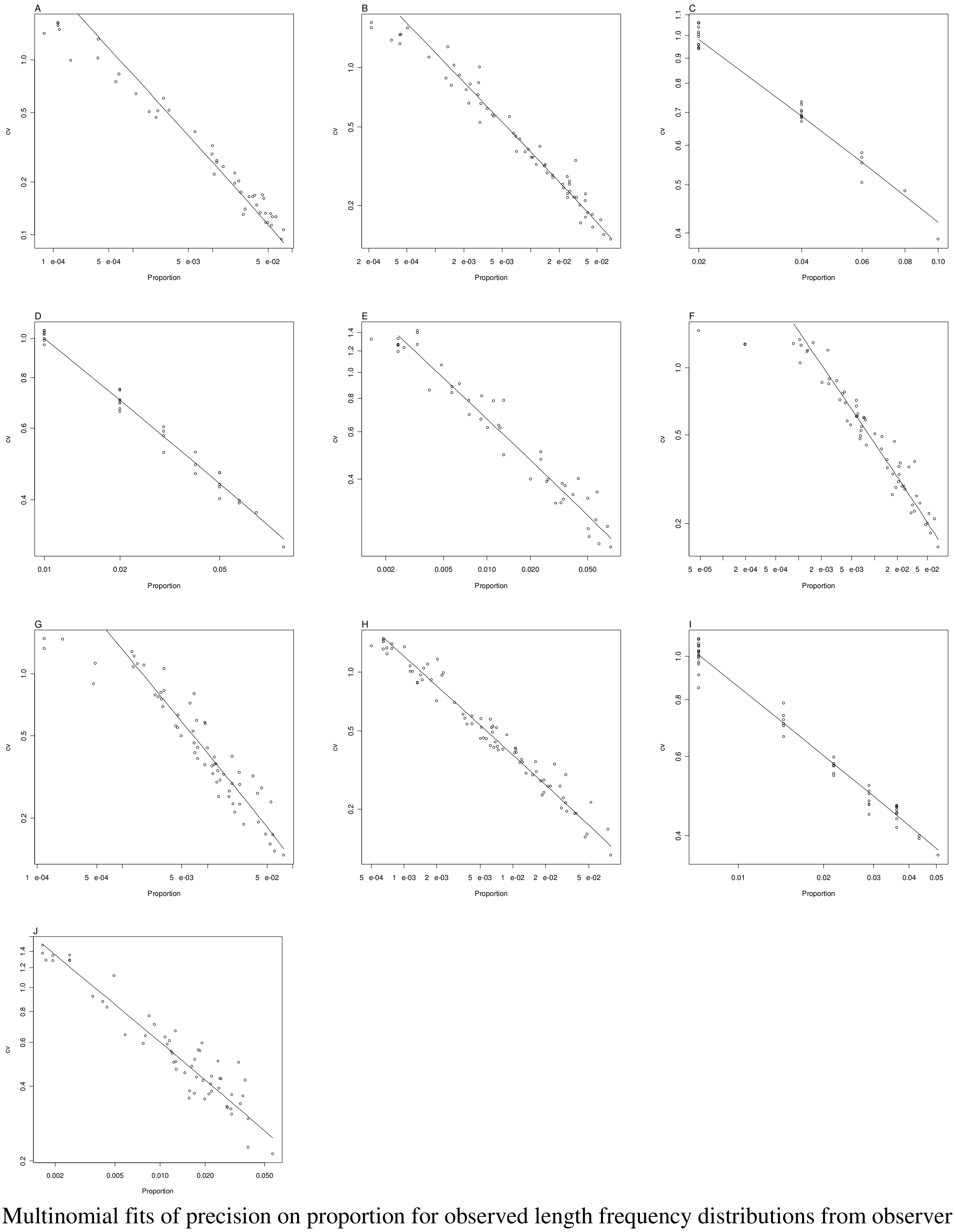
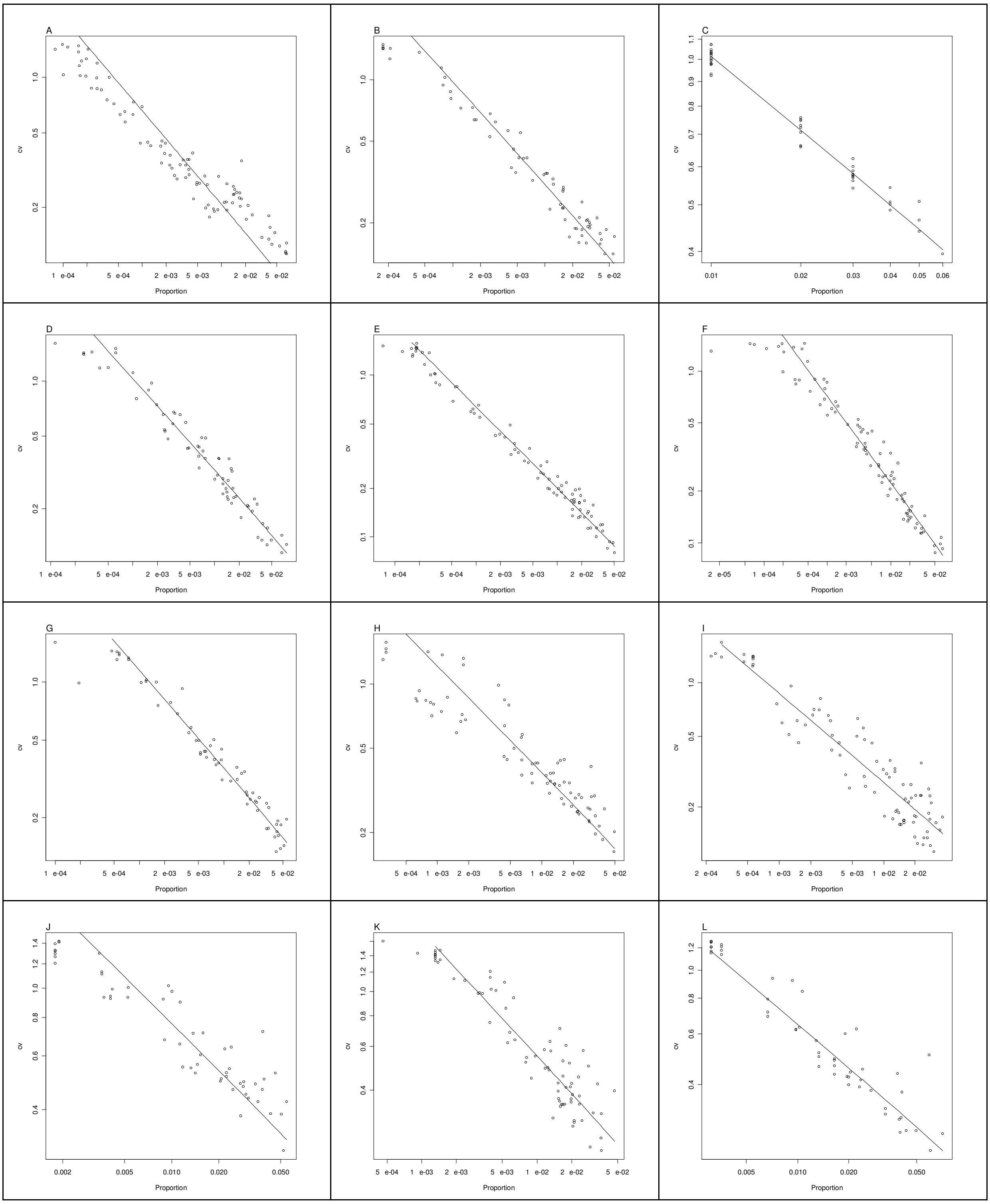
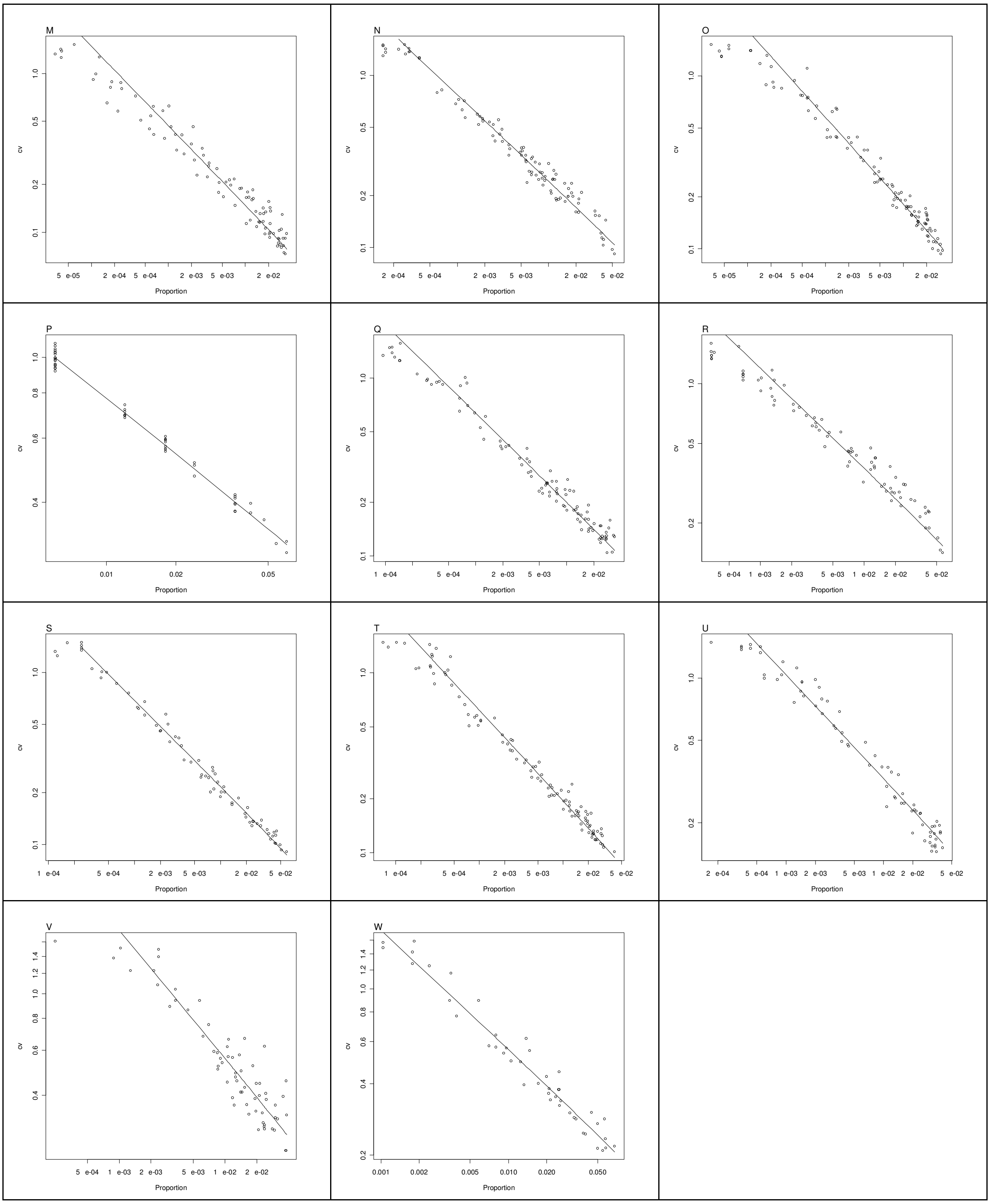
Appendix 1: Multinomial error structure and effective sample sizes for proportions at length.

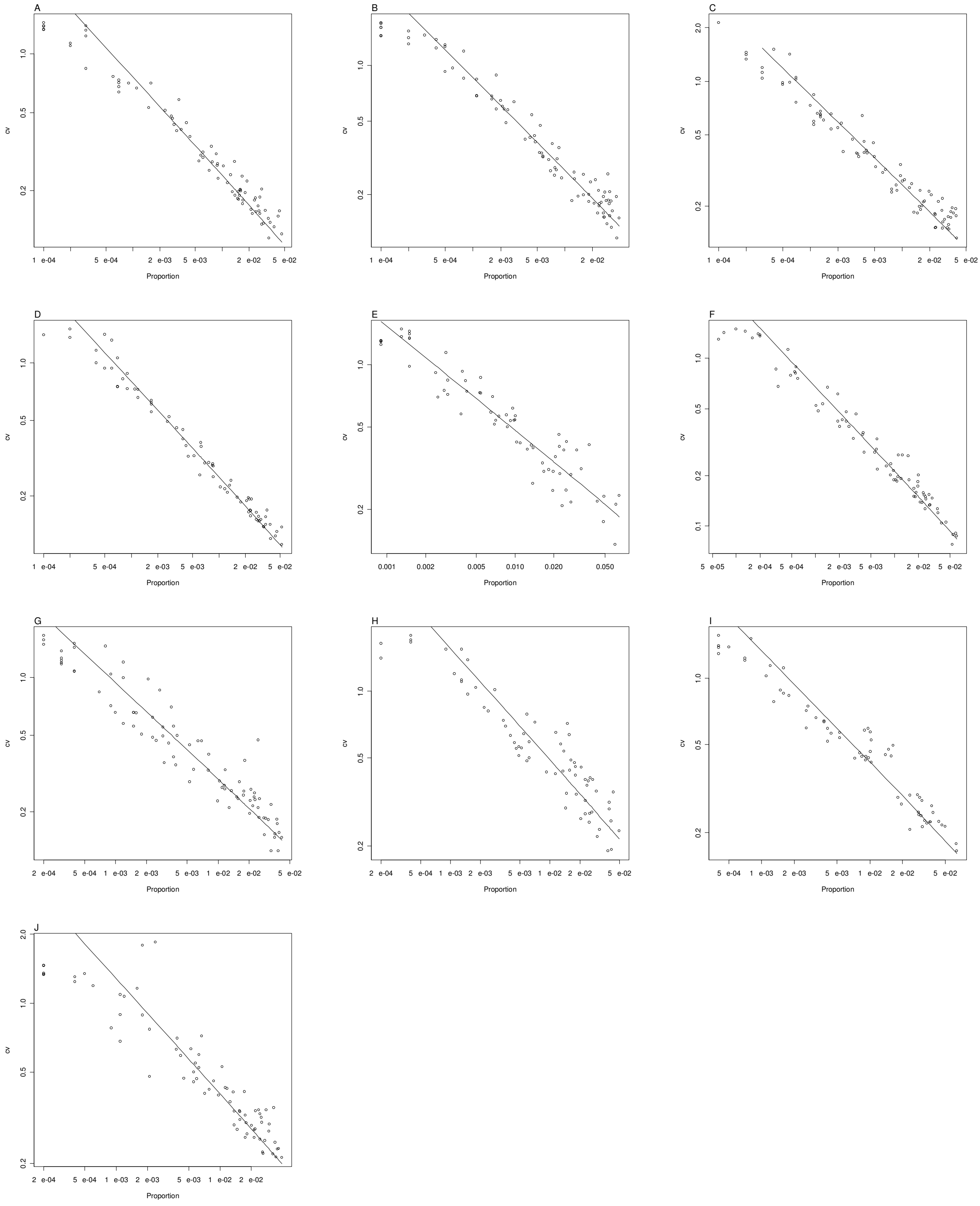


Multinomial fits of precision on proportion for observed length frequency distributions from observer sampling in SCI 1. (A – 1991_2, B – 1992_1, C – 1993_1, D – 1994_2, E - 1996_1, F – 1997_2, G – 1999_2, H – 2000_2, I – 2001_1, J – 2005_2).

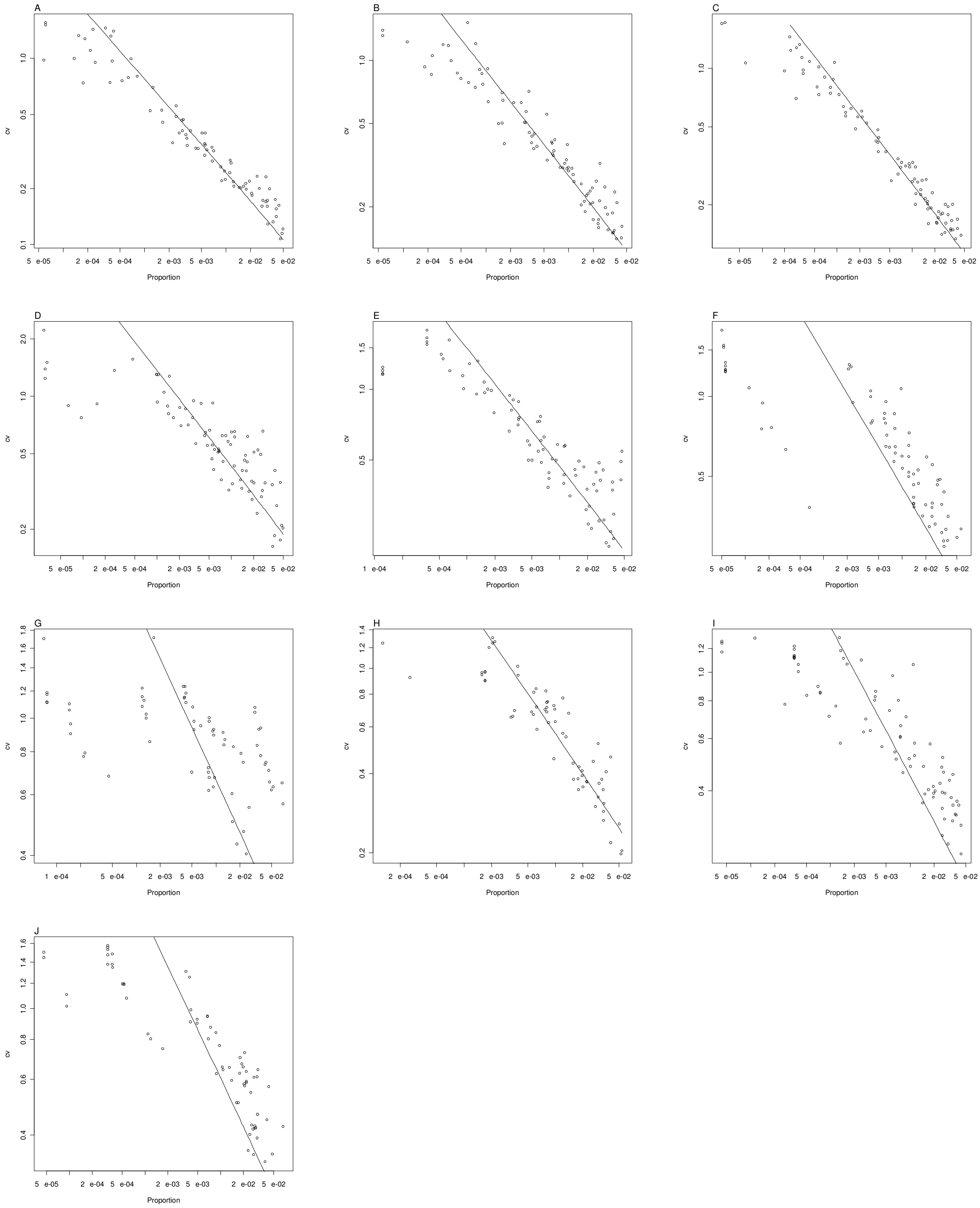

A
B
C
D
E
F
G
H
I
J
K
L
cv
Proportion



Multinomial fits of precision on proportion for observed length frequency distributions from observer sampling in SCI 2. (A – 1991_2, B – 1992_1, C – 1993_1, D – 1993_2, E – 1994_2, F – 1995_2, G – 1996_1, H – 1996_2, I – 1997_1, J – 1997_2, K – 1998_1, L – 1998_2, M - 1999_1, N – 1999_2, O – 2000_1, P – 2000_2, Q – 2001_1, R – 2001_2, S – 2001_1, T – 2002_2, U – 2003_1, V – 2003_2, W – 2005_1)



Multinomial fits of precision on proportion for observed length frequency distributions from research trawl sampling in SCI 1. (A – 1993_2, B – 1994_2, C – 1995_2, D - 1996_1, E – 1996_2, F – 1997_1, G – 1998_2, H – 2000_2, I – 2001_2, J – 2002_2)



Multinomial fits of precision on proportion for observed length frequency distributions from research trawl sampling in SCI 2. (A – 1993_2, B – 1994_2, C – 1995_2, D - 1999_2, E - 2000_1, F – 2000_2, G – 2003_2, H – 2004_2, I – 2005_2, J – 2006_2)

Working Document 8

Automating counting of Norway lobster using underwater video analysis.

Paulo Lobato Correia, Phooi Yee Lau, Paulo Fonseca and Aida Campos.

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