CNR Short Term Mobility Program

Visiting Researcher Report

Visit to Istituto di Scienze Marine (CNR-ISMAR), Ancona

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Dr Ian David Tuck

Institute of Water and Atmospheric Research (NIWA), Auckland, New Zealand

Purpose of visit: Assessment of Norway lobster, *Nephrops norvegicus*, in the Adriatic Sea using length-based assessment models

Background

Norway lobster, *Nephrops norvegicus*, (heron referred to by genus) is a benthic decapod crustacean living in burrows it constructs within muddy sediments. It is one of the most important fishery resources in the Adriatic Sea. The assessment of *Nephrops* populations is fraught with difficulties: 1) their burrowing behaviour and emergence patterns (individuals only leave their burrows to feed and mate and this happens in different proportions according to sex and season) heavily influence their availability to fishing gear, 2) there is a marked sexual dimorphism in growth parameters, 3) they are characterised by discontinuous growth which occurs only during moulting, ,making accurate age determination impossible, and 4) in the Adriatic Sea, they are the target of two fleets, the Italian and Croatian trawling fleets. For these reasons, the classical stock assessment methods based on the use of age classes are poorly successful, highlighting the need for explicitly length-based methods which consider length classes directly as well as treating sexes separately and yielding fleet-based results. The work carried out in New Zealand on *Metanephrops challengeri* is an example of this. *Metanephrops challengeri* is assessed using a Bayesian length-based approach by means of CASAL (C++ algorithmic stock assessment laboratory; Bull et al. 2012). CASAL is a very flexible platform which allows the specification of complex models, both single and multi-species, taking into account numerous variables and using information by length directly without slicing it into ages. It can generate point estimates of the main parameters of interest as well as likelihood profiles and Bayesian posterior distributions, and can project stock status into the future as well as calculate outputs of interest to management e.g. F_{max}, $F_{0.1}$, MSY (Bull et al., 2012).

The main difference between an age-based and a size-based model lies in the way growth is specified. In a size-based model growth is the process by which fish move between subsequent size classes. This requires good estimates of growth as they will influence (and possibly confound) estimates of fishing mortality (Dobby & Hillary, 2008). Growth and the uncertainty about it is one of the major impediments to a good assessment of *Nephrops* stocks. In CASAL growth can be specified in three different ways: (i) the Francis parameterisation (Francis, 1988) which makes use of growth increments from the von Bertalanffy growth function, (ii) an alternative Francis parameterisation with exponential decay and (iii) a fixed user-defined transition matrix. A number of growth functions have been estimated for Adriatic *Nephrops* (from Pomo and Non Pomo) throughout the years and were used as fixed input parameters within the CASAL models described below.

A similar methodology was applied to European hake, whose ageing is uncertain: this assessment too is described here as it shows how different model specifications can be constructed in CASAL; this work could ultimately benefit the *Nephrops* assessment.

In this report we describe three CASAL assessments which comprised the bulk of the work carried out during my visit in Ancona: two *Nephrops* stocks (Pomo and Non Pomo) and one European hake stock (GSA 17), each with different characteristics

1. Norway lobster, *Nephrops norvegicus*, in GSA 17

A stock assessment of Adriatic Norway lobster, *Nephrops norvegicus*, was undertaken using a length based model with the CASAL software. Norway lobster are distributed across a range of areas within the Adriatic, with life history characteristics (growth, size at maturity, population density) being markedly different between the Pomo/Jabuka Pit area ("Pomo", slower growth and smaller size at maturity) than elsewhere ("Non Pomo"). The assessment was therefore conducted in two separate models (one for the Pomo region, and one for the stock outside Pomo, but within international waters only) to account for this. The Norway lobster stock outside Pomo, and within Croatian territorial waters was not examined, as there are no landings data currently available for this region and the fishery is very different, occurring in channel areas and/or with traps.

Similar model structures were applied in each assessment, reflecting the seasonal patterns in Norway lobster sex ratio, related to moulting and reproductive behaviour. Sex was included in the model partition to allow for different availability of the two sexes. Catches and surveys were divided into two time steps reflecting periods of the year when both sexes are relatively equally available to the fishery (April to July), and when mature females are far less available than males (August to March). Adoption of these time steps means that the model year runs from April to March.

Preliminary length based assessment model for Norway lobster (Nephrops norvegicus) in the Pomo Pit

The Pomo Pit Norway lobster stock was modelled over the period April 1985 to March 2014 (model years 1985 - 2013), with model year labelled by the calendar year that it starts in.

The Pomo Pit stock extends from international waters into the Croatian territorial sea. Two distinct fisheries operate in these areas and, given that Norway lobster do not migrate, it was decided to consider the two areas as separate in the model. Data were therefore collated by year, time step and area. Data available for the Pomo Pit model are listed in Table 1.

Italian landings data were allocated to time step and area on the basis of analysis of VMS data examining the distribution of fishing effort and landings, and applying the patterns to historical years. Croatian landings data were allocated to time step and area applying the seasonal pattern in catch observed for fishery Zones C and D in 2008 - 2010 to all previous years. Commercial fishery and trawl survey selectivities were assumed to be the same in the two areas, but varied between time step and survey (although the selectivity was assumed to remain constant between the earlier GRUND 2 and later GRUND surveys). No commercial sampling data (Length frequency distributions) were available for the Croatian fishery.

A single recruitment index was estimated (applied to both areas), with the proportion of total recruits going to each area estimated within the model (assumed constant over time). Growth was fixed on the basis of data contained in Froglia and Gramitto (1988). Natural mortality was applied as a vector by length, calculated by sex using PRODBIOM (Abella et al., 1997) and derived from the von Bertalanffy growth function and the length-weight relationship.

At the time of analysis, no length frequency was available for the UWTV survey, and so in this preliminary model development the UWTV survey was excluded. The UWTV trawl survey data were available but their use are still under exam.

In the initial runs, capped logistic selectivities were applied for males, and double normal selectivities for females, allowing for differences in overall catchability between the sexes, and reduced availability of mature (larger) females while ovigerous. The length frequency data showed evidence that the GRUND survey was not catching large males (which were caught by the commercial fishery), implying reduced availability to the survey (potentially related to spatial targeting by the fishery). A double normal selectivity was therefore also applied for males in the GRUND survey.

Table 1: Data available for Pomo Pit Norway lobster assessment. Years represent overall year range, but data may not be available for all intermediate years.

	Italian area	Croatian area
Landings	Step 1 (1985-2013) Step 2 (1985-2013)	Step 1 (1985-2013) Step 2 (1985-2013)
Length frequency of commercial catches	Step 1 (2007-2013) Step 2 (2006-2013)	
Surveys	MEDITS (1996-2013) GRUND (2000-2007) GRUND2 (1985-1998) UWTV (2009-2013) UWTV trawl survey(2009-2013)	MEDITS (1997-2013) GRUND (2001-2007) UWTV (2009-2013) UWTV trawl survey(2009-2013)
Length frequency of survey catches	MEDITS (1996-2013) GRUND (2000-2007) GRUND2 (1993-1998)	MEDITS (1996-2013) GRUND (2004-2007)
Growth	From Froglia & Gramitto 1988	
Maturity	From Froglia & Gramitto 1981	
Length weight relationship	From Froglia & Gramitto 1988	
Natural mortality	Calculated with PRODBIOM (Abella et al., 1997)	

The annual cycle of processes applied within the population model are shown in Table 2.

Table 2: Annual cycle of the population model for Pomo Pit, 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.

Time step	Period	Process	Proportion in time step
1	April - July	Growth	
		Natural mortality	0.333
		Fishing mortality	From landings
2	August - March	Recruitment	1
		Maturation	1
		Natural mortality	0.667
		Fishing mortality	From landings

Final preliminary model

Fits to the Pomo Pit model are presented below, with key parameter estimates provided in Table 3. The model estimates SSB_0 for the Pomo Pit stock of 15900 tonnes, with SSB_{2013} estimates at 5200 tonnes, 33% of SSB_0. The model estimates 83% of the recruitment (by numbers) occurs in the Italian area. Fits to the survey indices were variable (Figure 1), and the model estimated a general declining biomass trajectory, with short term increases associated with strong recruitment in the late 1980s and mid 2000s (Figure 2). The exploitation rate (catch / SSB) increased slowly during the 1980s, remained stable during the 1990s, but increased and became more variable during the 2000s (Figure 2).

Estimated selectivities (Figure 3) follow expected patterns, in that male availability was considerably higher than females during time step 2. Average fits to the length distributions were good (Figure 4 and Figure 5), but fits to individual samples were more variable (Figure 6 to Figure 14).

The likelihood profile for SSB_0 showed a clear minimum at about 16000 tonnes, and was "U" shaped (Figure 15). There was some conflict between the data sets, which warrants further investigation.

Annual F_{bar} was estimated from model outputs (Figure 16), and for the whole Pomo Pit stock, shows a period of low stable exploitation up until the end of the 1990s, followed by a period of higher more variable exploitation. The pattern in the Italian area matches the overall pattern well, while the exploitation in the Croatian area appears to have increased rapidly in the most recent years. Plots of exploitation against biomass (Figure 17 to Figure 19) suggest F_{bar} increased gradually as biomass declined, but became higher and more variable once biomass fell below a particular level. The high estimated exploitation in the Croatian area in 2013 is associated with a low biomass.

Next steps

Having developed a preliminary model, the next steps are to confirm the assumptions that had to be made (particularly relating to Croatian landings data) are appropriate, and investigate the sensitivity of the model to different data sets. MCMC approaches can be used to examine uncertainty in the model results.

Table 3: Key estimated parameters from the Pomo Pit model.

Parameter	Estimate
SSB_0	15895.3 tonnes
SSB_{2013}	5206.53 tonnes
$SSB_{2013/}$ SSB_0	0.3275
Proportion recruitment to Italian area	0.834471
Survey q values	
GRUND	0.148257
GRUND2	0.115953
MEDITS	0.0248663

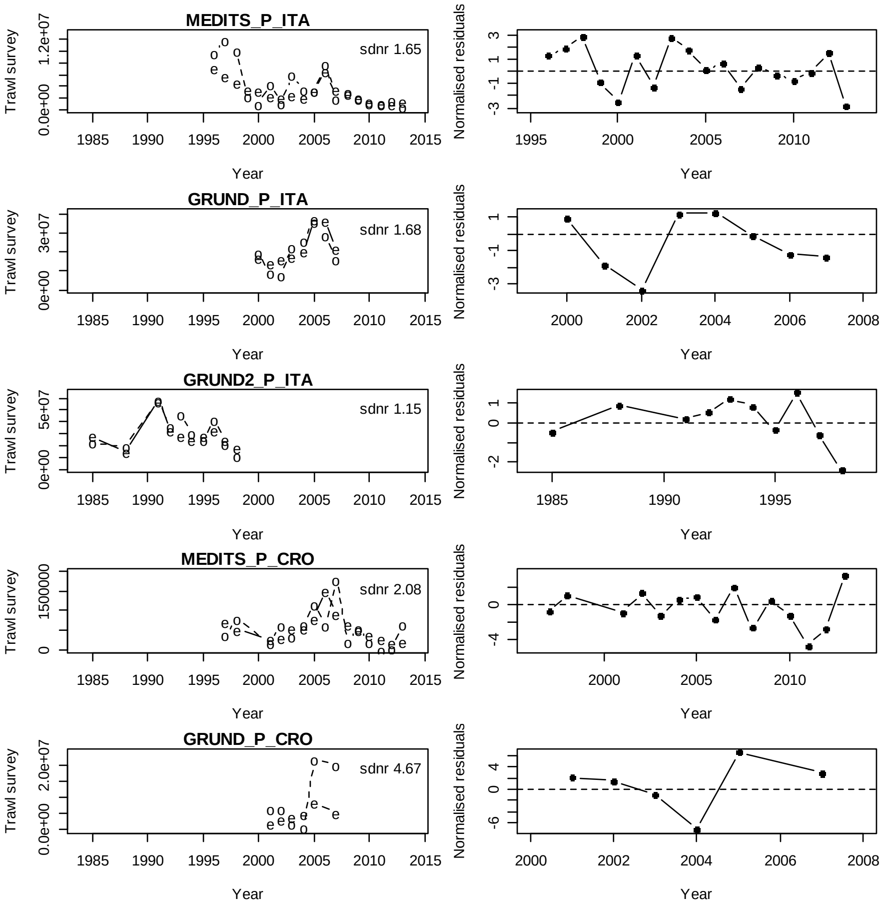

Figure 1: Fits to trawl survey indices (left column) and normalised residuals (right column) for each survey for the Pomo Pit.

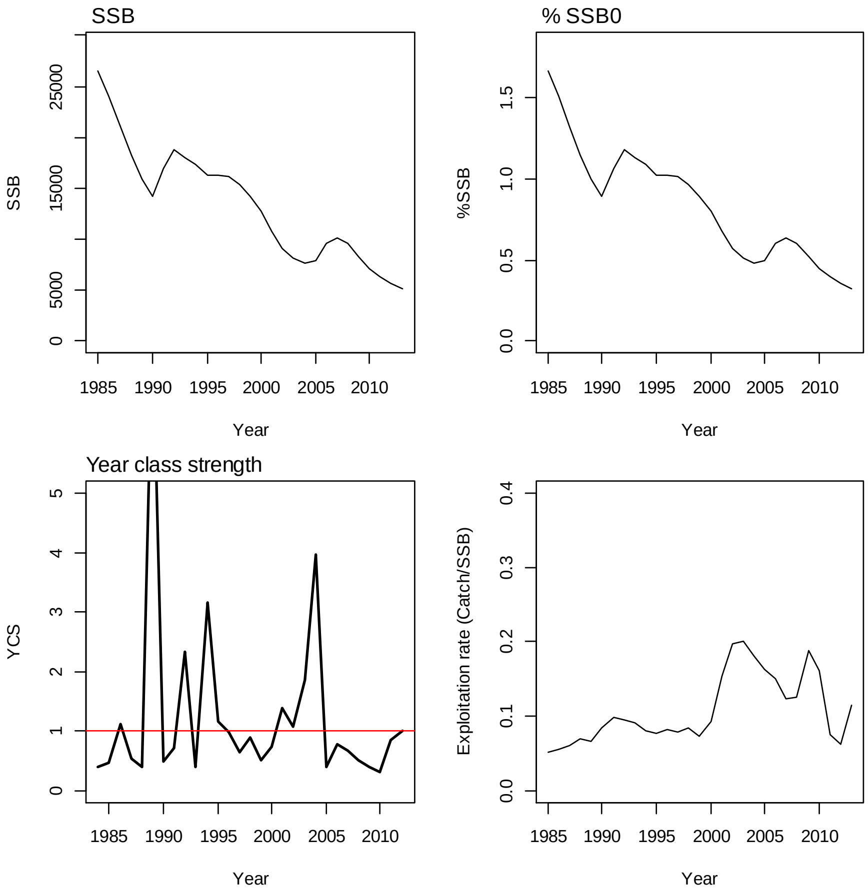

Figure 2: Trajectory of estimated spawning stock biomass (SSB)(top left), SSB as a percentage of SSB0 (top right), year class strength (YCS)(bottom left) and explotation rate (catch / SSB)(bottom right) for the Pomo Pit.

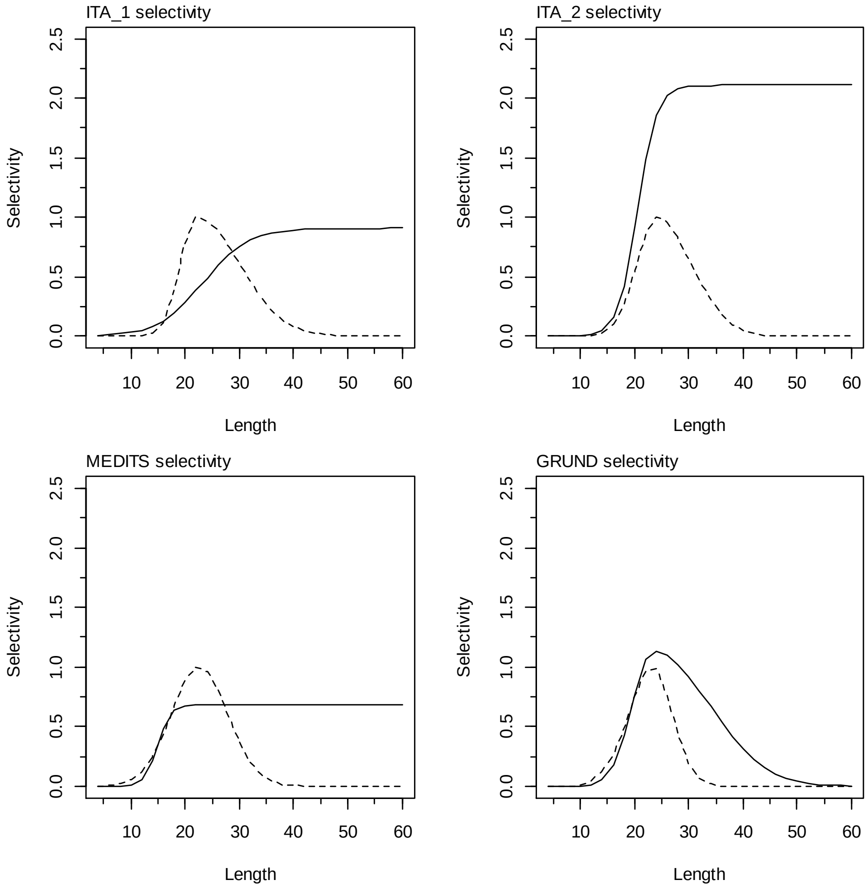

Figure 3: Fishery and survey selectivity curves for SCI 3 NT_0.15. Solid line – females, dotted line – males.

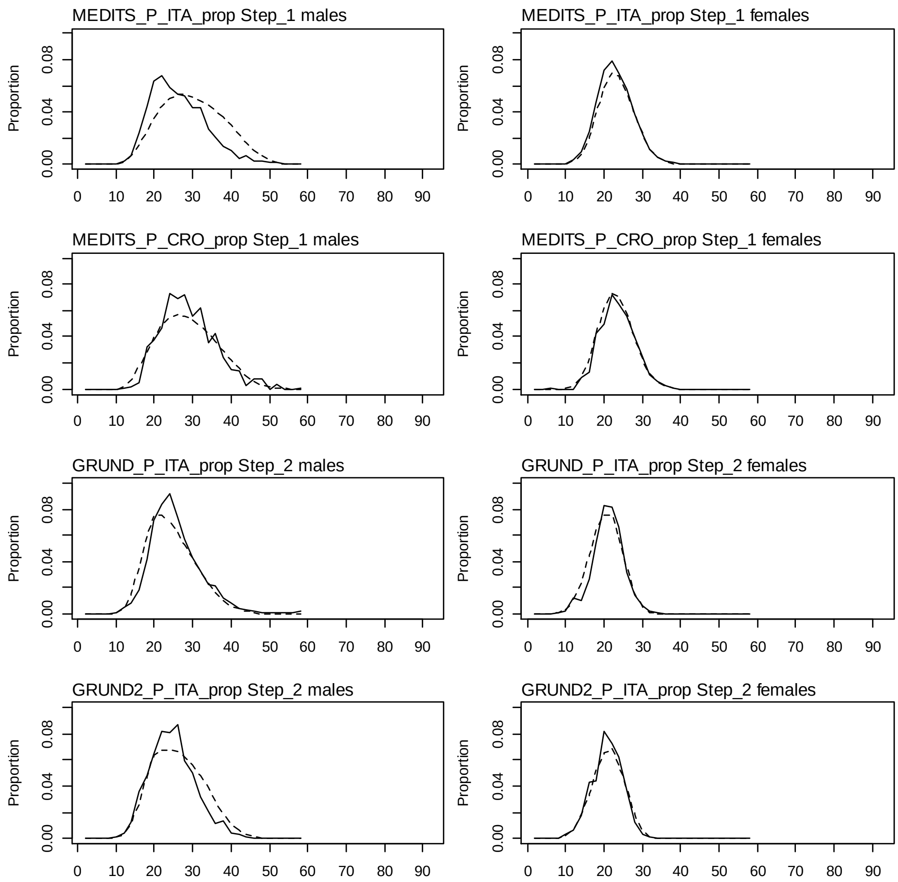

Figure 4: Average observed (solid line) and fitted (dashed line) length frequency distributions for MEDITS (Italian and Croatian areas), GRUND (Italian area) and GRUND2 (Italian area) survey length frequency samples for Pomo Pit.

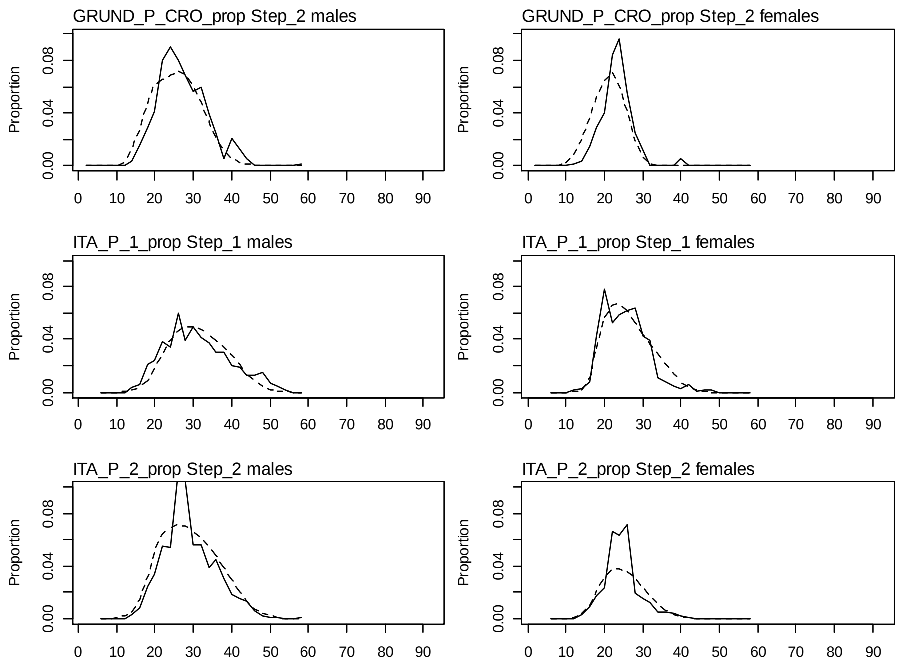

Figure 5: Average observed (solid line) and fitted (dashed line) length frequency distributions for GRUND (Croatian area) survey and Italian commercial fishery length frequency samples for Pomo Pit.

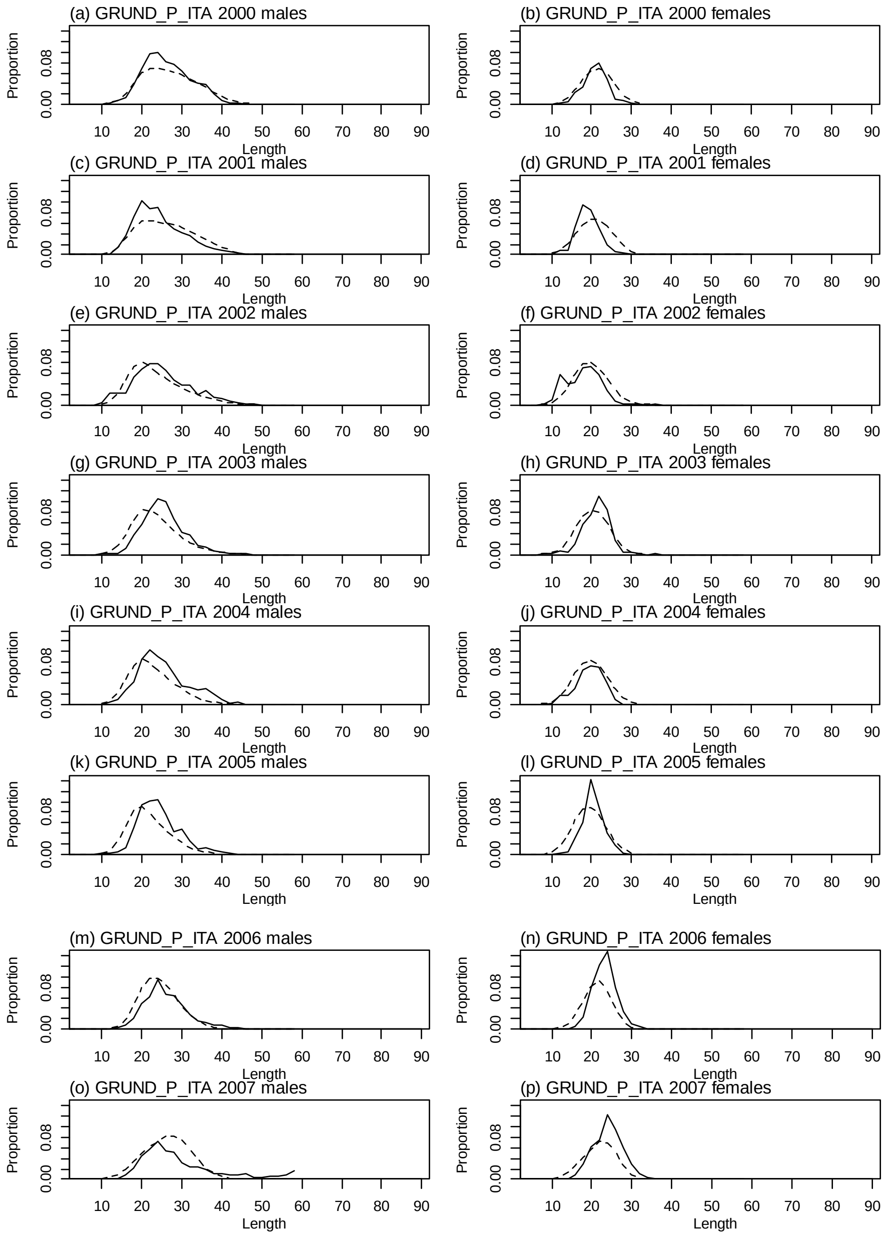

Figure 6: Observed (solid line) and fitted (dashed line) length frequency distributions for survey length frequency samples, GRUND survey (Italian area).

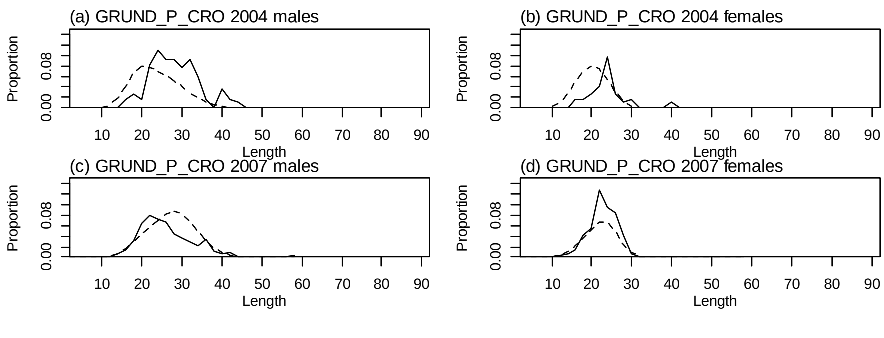

Figure 7: Observed (solid line) and fitted (dashed line) length frequency distributions for survey length frequency samples, GRUND survey (Croatian area).

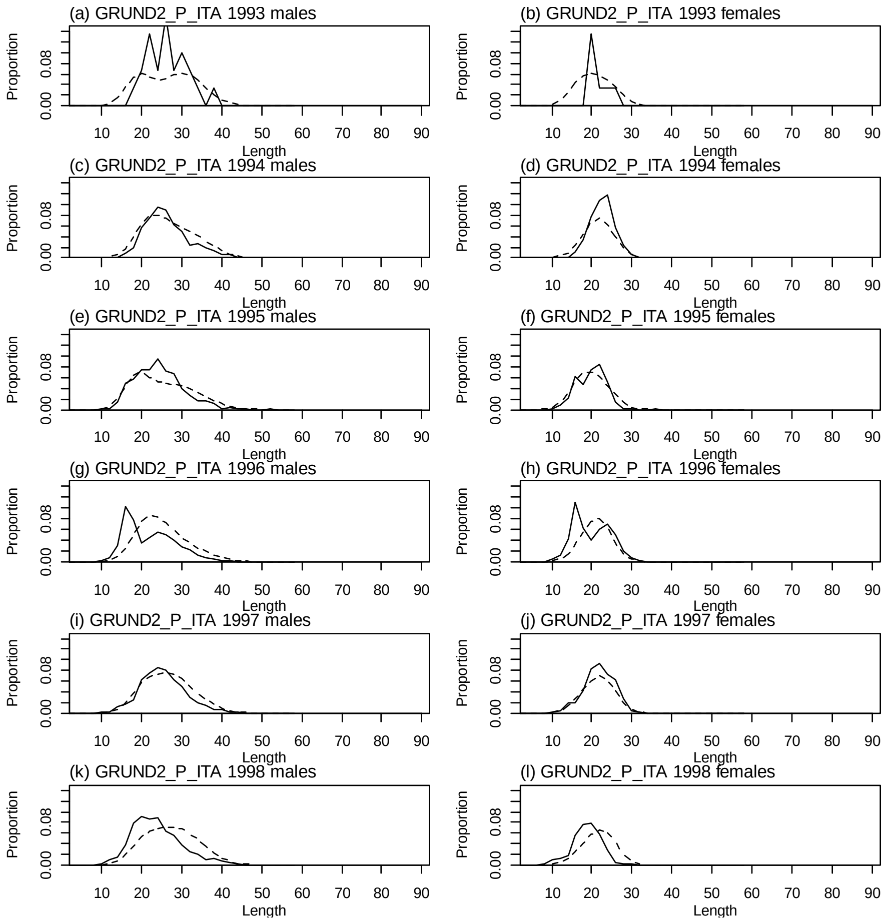

Figure 8: Observed (solid line) and fitted (dashed line) length frequency distributions for survey length frequency samples, GRUND2 survey (Italian area).

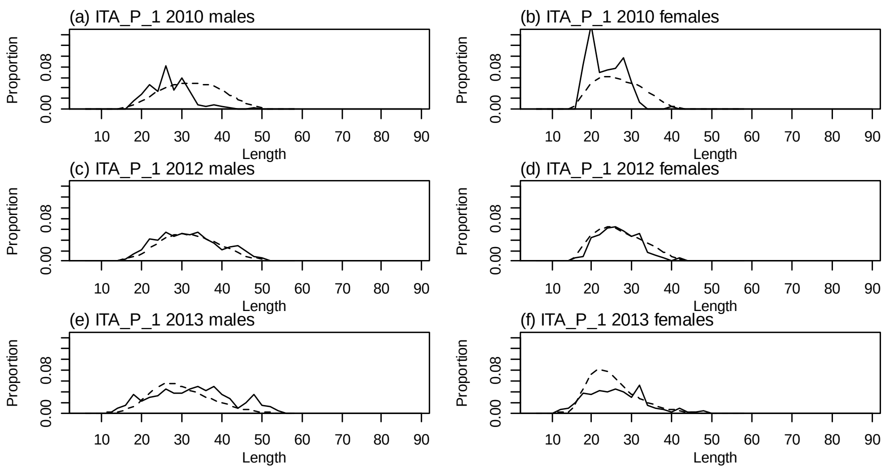

Figure 9: Observed (solid line) and fitted (dashed line) length frequency distributions for commercial catch length frequency samples in time step 1 (Italian area).

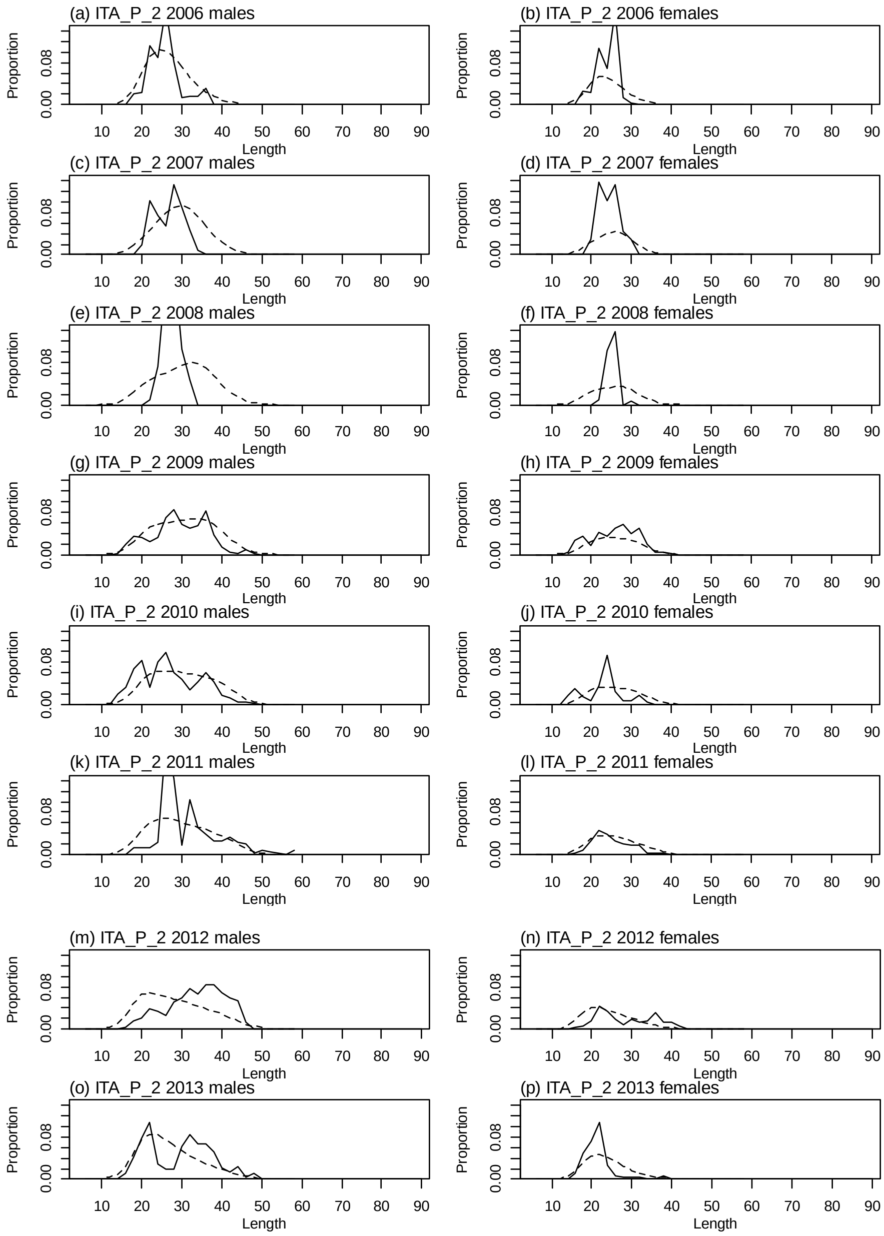

Figure 10: Observed (solid line) and fitted (dashed line) length frequency distributions for commercial catch length frequency samples in time step 2 (Italian area).

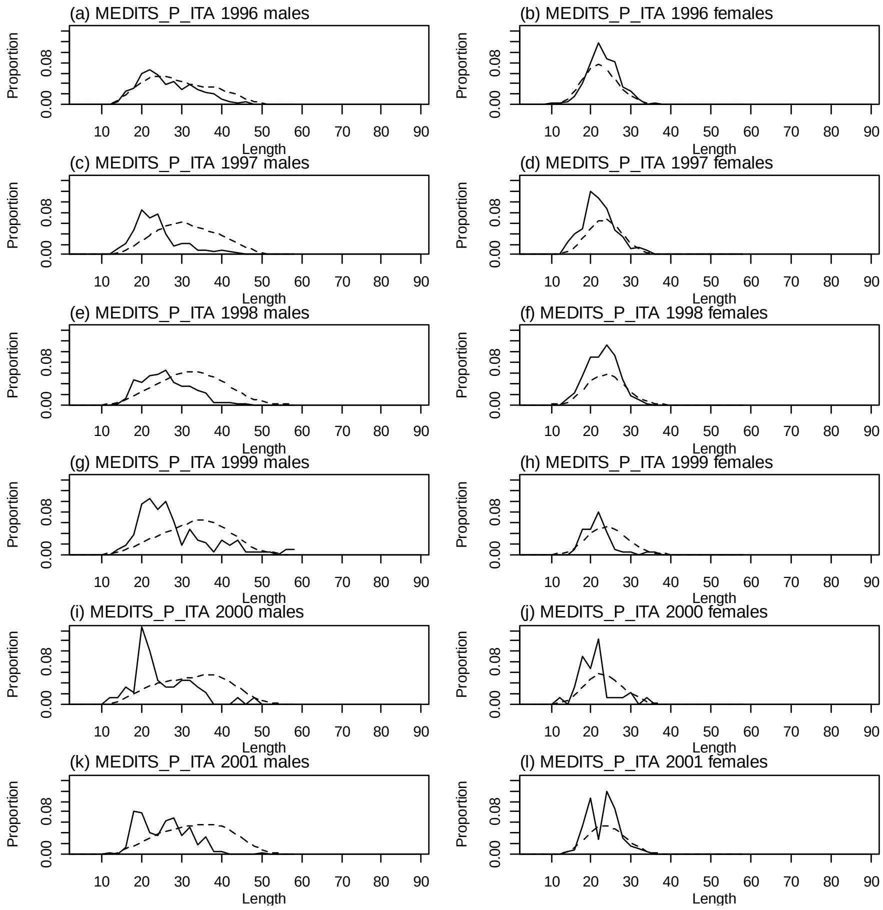

Figure 11: Observed (solid line) and fitted (dashed line) length frequency distributions for survey length frequency samples, MEDITS survey (1996-2001; Italian area).

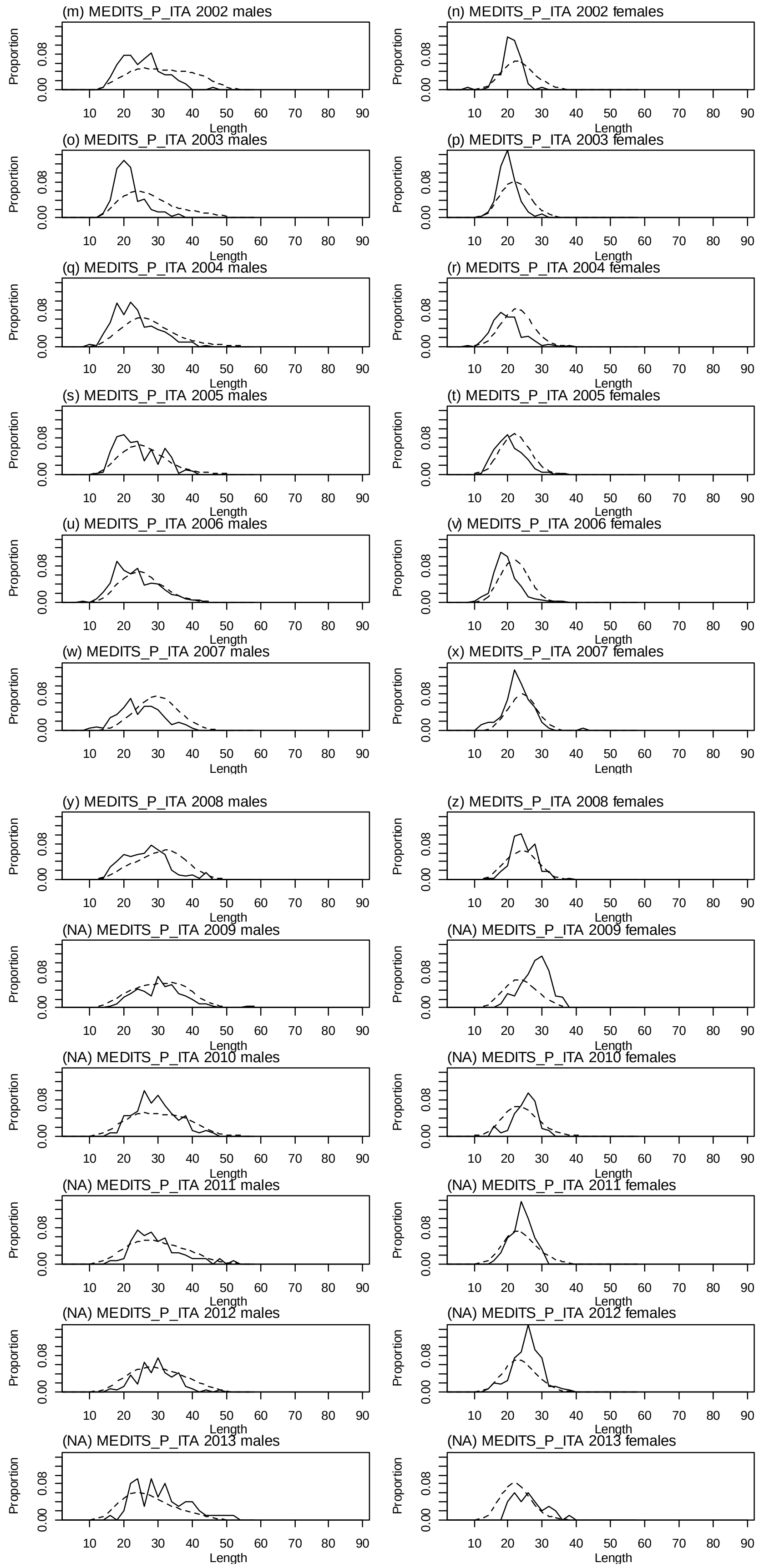

Figure 12: Observed (solid line) and fitted (dashed line) length frequency distributions for survey length frequency samples, MEDITS survey (2002-2013; Italian area).

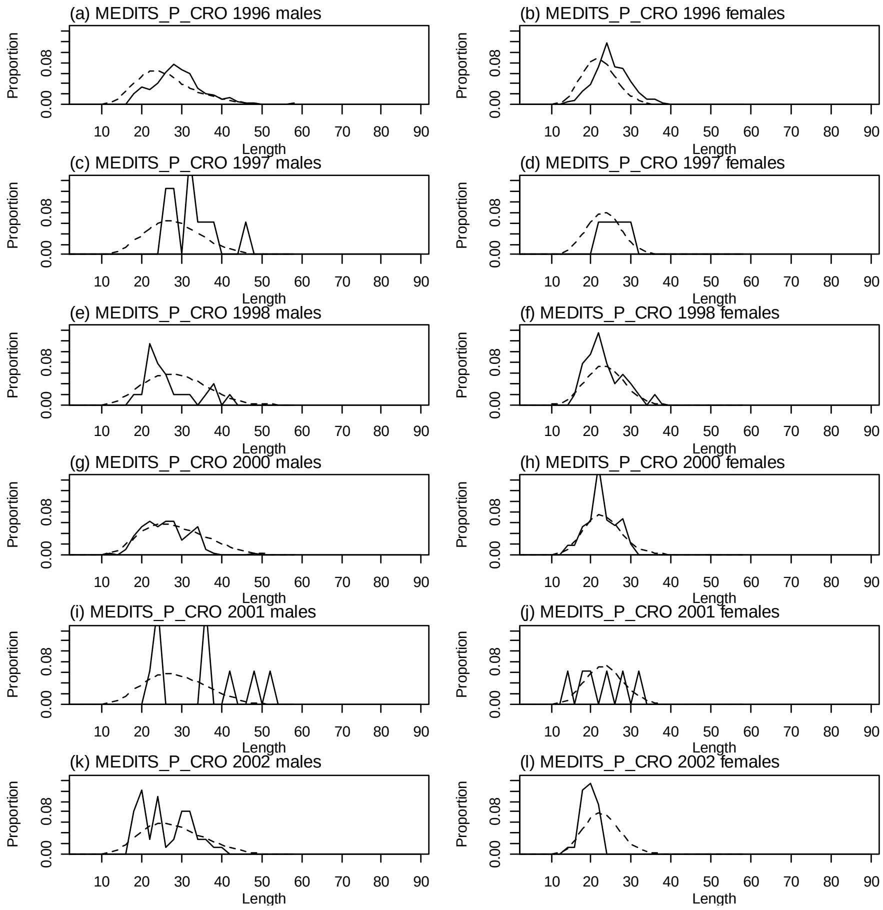

Figure 13: Observed (solid line) and fitted (dashed line) length frequency distributions for survey length frequency samples, MEDITS survey (1996-2002; Croatian area).

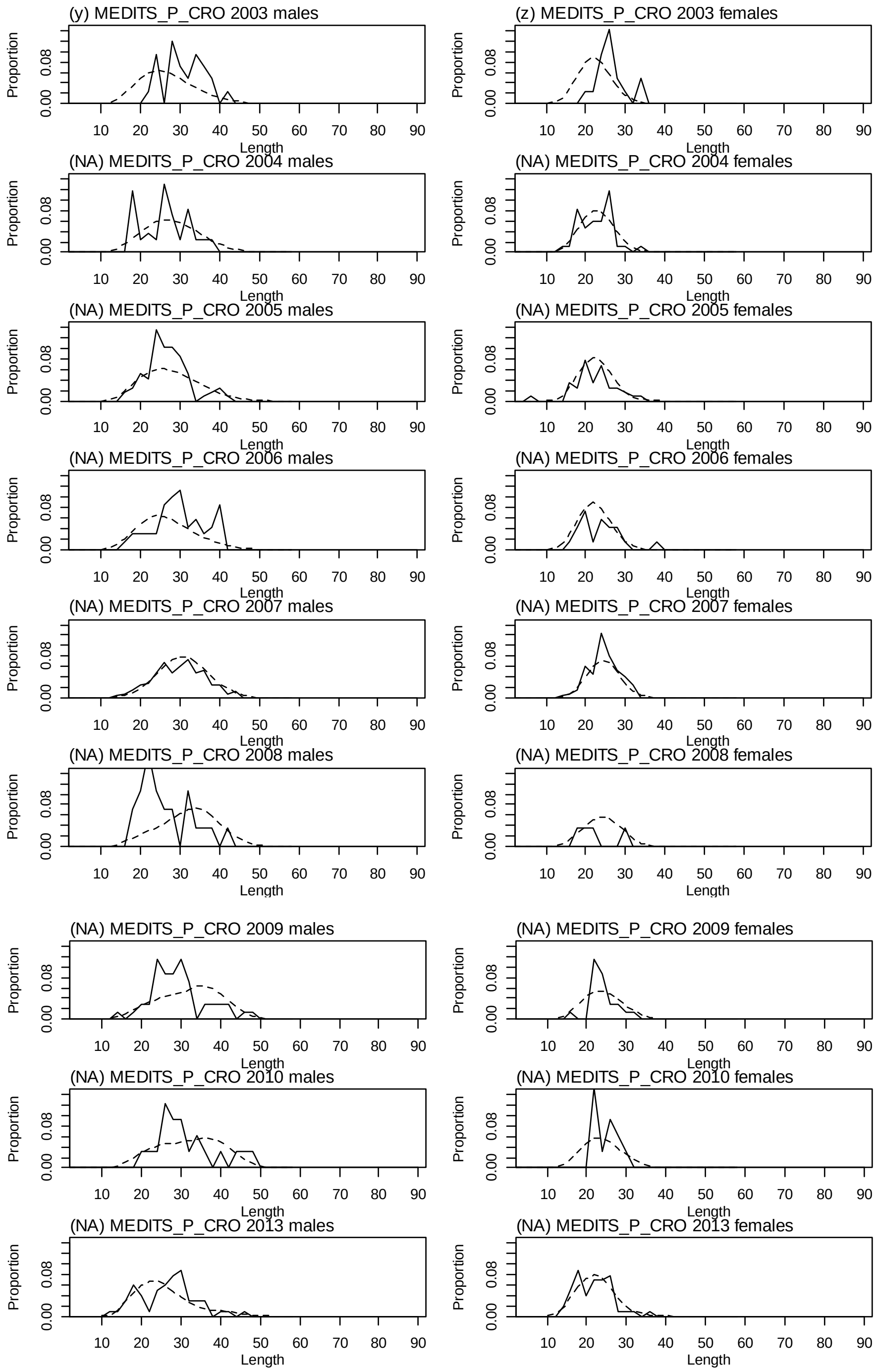

Figure 14: Observed (solid line) and fitted (dashed line) length frequency distributions for survey length frequency samples, MEDITS survey (2003-2013; Croatian area).

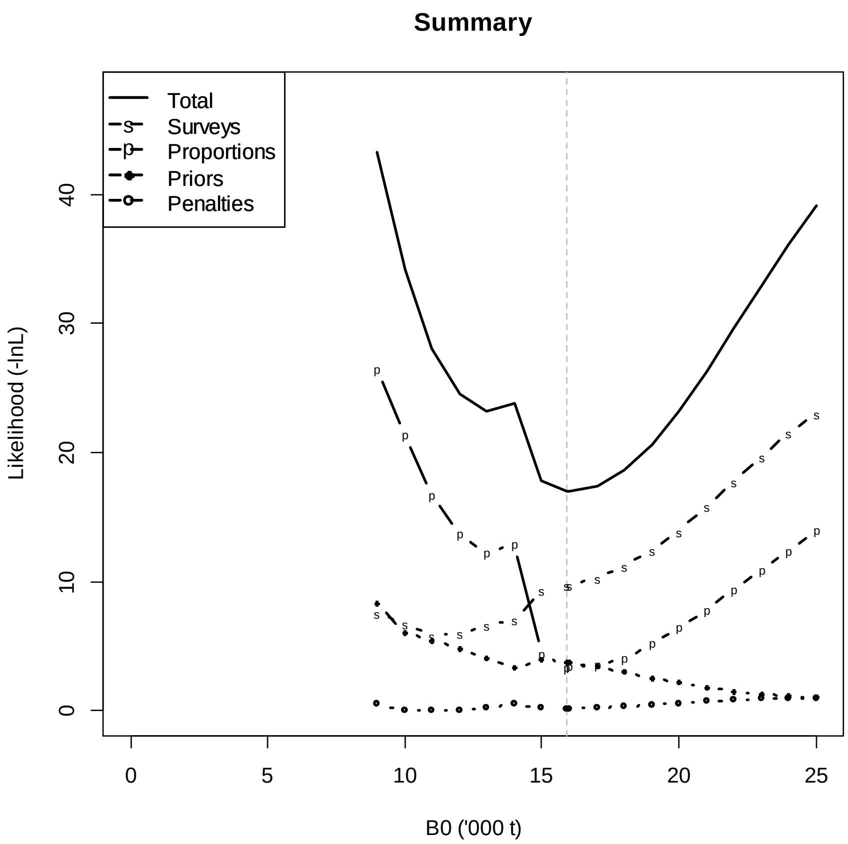

Figure 15: Likelihood profiles for the Pomo Pit when B_0 is fixed in the model. Figure shows the overall profile, and contributions from the surveys, proportions at length, priors and penalties. Vertical dashed line represents MPD.

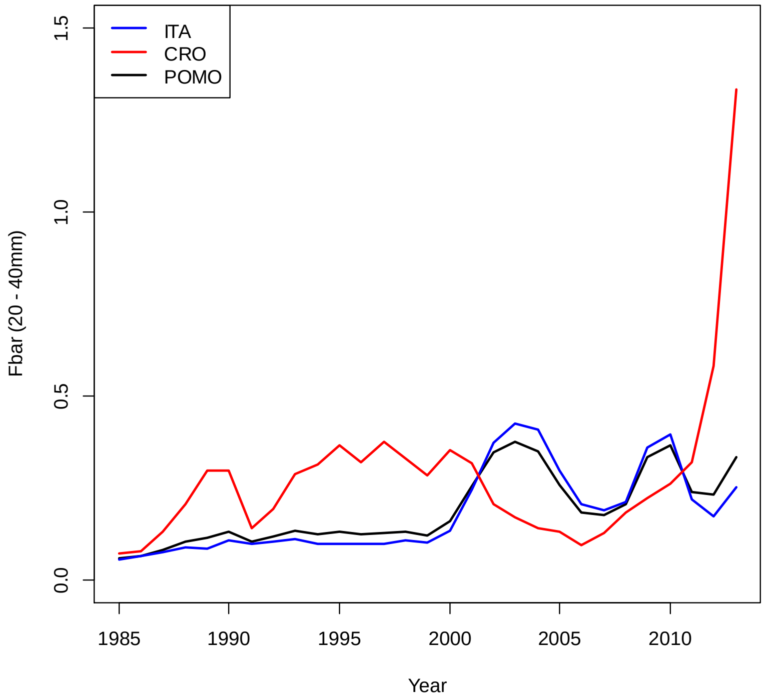

Figure 16: Plot of estimated F_{bar} (20 – 40 mm) over the modelled period 1985 to 2013, for the whole stock, and Italian and Croatian areas separately.

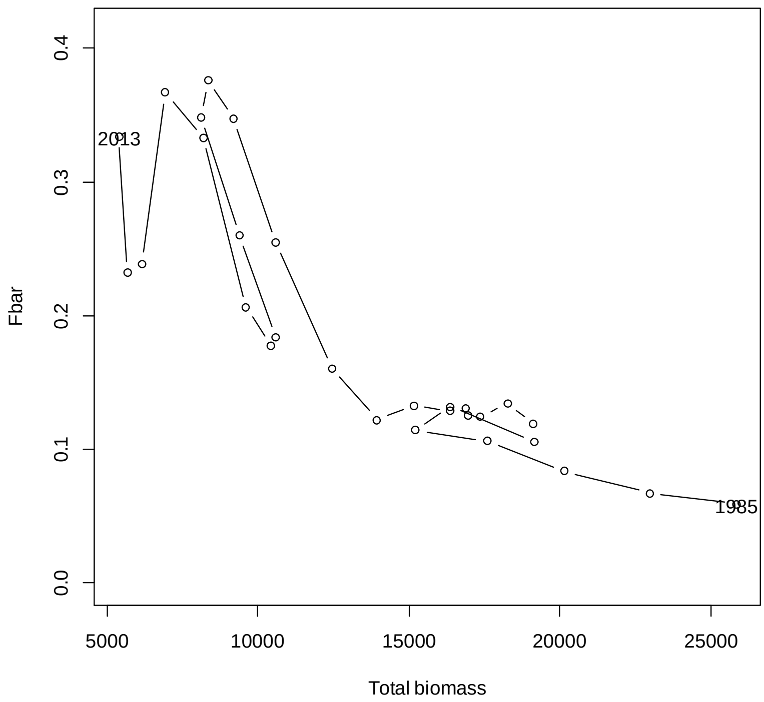

Figure 17: Plot of estimated F_{bar} (20 – 40 mm) against total stock biomass for the whole Pomo stock over the modelled period 1985 to 2013.

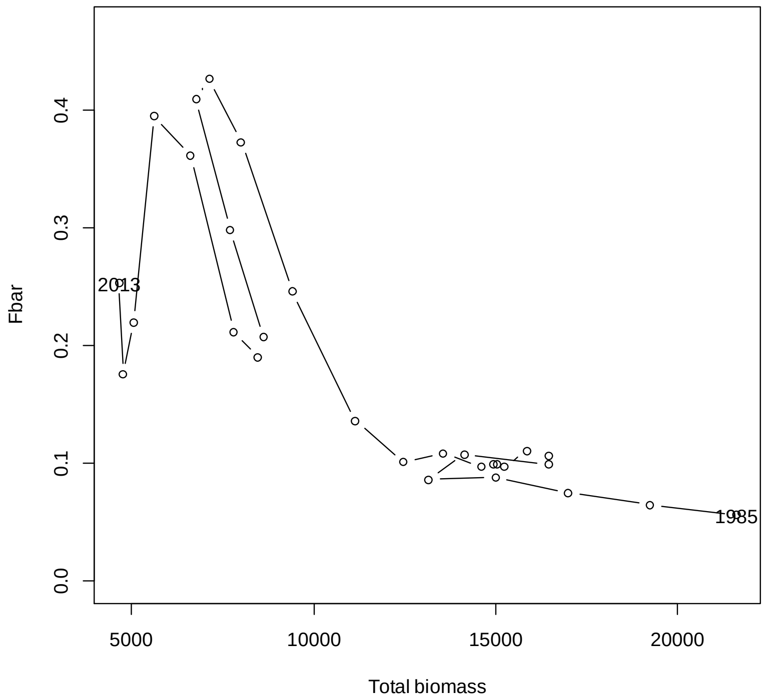

Figure 18: Plot of estimated F_{bar} (20 – 40 mm) against total stock biomass for the Italian area of the Pomo stock over the modelled period 1985 to 2013.

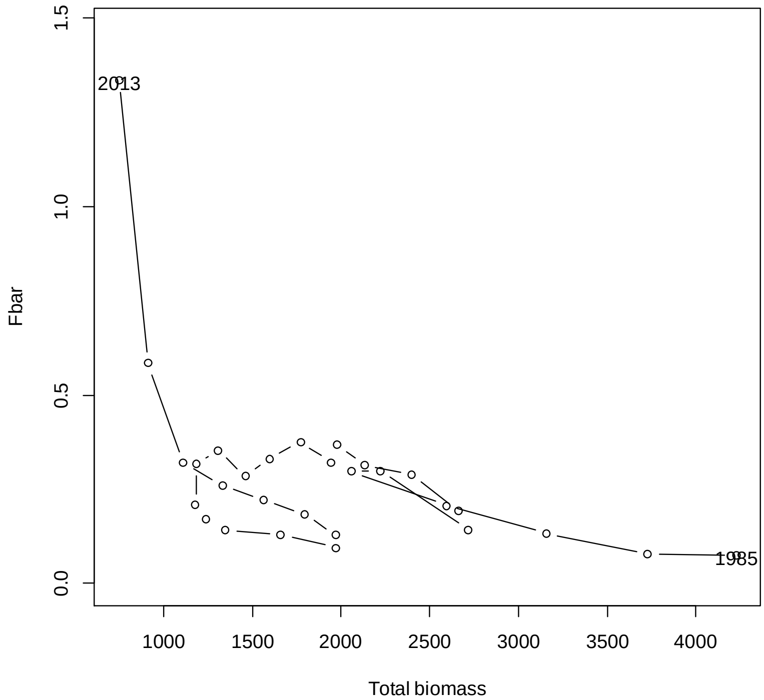

Figure 19: Plot of estimated F_{bar} (20 – 40 mm) against total stock biomass for the Croatian area of the Pomo stock over the modelled period 1985 to 2013.

Preliminary length based assessment model for Norway lobster (*Nephrops norvegicus*) outside the Pomo Pit ("Non Pomo")

The Nephrops stock of GSA 17 outside Pomo and within international waters was modelled over the period April 1985 to March 2014 (model years 1985 - 2013), with model year labelled by the calendar year that it starts in.

In this assessment we consider the Non Pomo stock to extend into Italiana and international waters only, thus one single fishery, the Italian trawl fishery, was represented in the model. Data available for the Non Pomo area are listed in Table 1.

Italian landings data were allocated to time step and area on the basis of analysis of VMS data examining the distribution of fishing effort and landings, and applying the patterns to historical years. Commercial fishery and trawl survey selectivities varied between time step and survey (although the selectivity was assumed to remain constant between the earlier GRUND 2 and later GRUND surveys).

Growth was fixed on the basis of data contained in Froglia and Gramitto (1988). Natural mortality was applied as a vector by length, calculated by sex using PRODBIOM (Abella et al., 1997) and derived from the von Bertalanffy growth function and the length-weight relationship.

Table 4: Data available for the non Pomo *Nephrops* assessment. Years represent overall year range, but data may not be available for all intermediate years.

Landings	Time step 1 (1985-2013) Time step 3 (1985-2013)
Length frequency of commercial catches	Time step 1 (2007-2013) Time step 3 (2006-2013)
Surveys	MEDITS (1996-2013) GRUND (2000-2007) GRUND2 (1985-1998) UWTV (2009-2013) UWTV trawl survey(2009-2013)
Length frequency of survey catches	MEDITS (1996-2013) GRUND (2000-2007) GRUND2 (1993-1998)
Growth	From Froglia & Gramitto 1988
Maturity	From Froglia & Gramitto 1981
Length weight relationship	From Froglia & Gramitto 1988
Natural mortality	Calculated with PRODBIOM (Abella et al., 1997)

At the time of analysis, no length frequency was available for the UWTV survey, and so in this preliminary model development the UWTV survey was excluded. The UWTV trawl survey data were available but their use are still under exam.

In the initial runs, capped logistic selectivities were applied for males, and double normal selectivities for females, allowing for differences in overall catchability between the sexes, and reduced availability of mature (larger) females while ovigerous. The length frequency data showed evidence that the GRUND survey was not catching large males (which were caught by the commercial fishery), implying reduced availability to the survey (potentially related to spatial targeting by the fishery). A double normal selectivity was therefore also applied for males in the GRUND survey. A separate selectivity was estimated for the GRUND2 survey; but the different options are still under investigation.

The annual cycle of processes applied within the population model are shown in Table 2. They are a little different to those assumed in the Pomo pit model: a third time step was added in between the original two used for the Pomo pit. This time step had no mortality and no time but marked an characterised an growth period.

Table 5: Annual cycle of the population model for Non Pomo GSA17, 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.

Time step	Period	Process	Proportion in time step
1	April - July	Natural mortality	0.333
		Fishing mortality	From landings
2	Timeless between TS1 and TS2	Growth	
3	August - March	Recruitment	1
		Maturation	1
		Natural mortality	0.667
		Fishing mortality	From landings

Next steps

This preliminary model still needs some work before results can be discussed and evaluated: more attention needs to be paid to the selectivity specifications given within the model (e.g. should GRUND2 and GRUND have different selectivities?).

Once the preliminary model is fully developed, the next steps will be to:

(i) confirm the assumptions that had to be made are appropriate,
(ii) retrieve Croatian data – which will necessarily have to include the trap fishery – and implement a second area as for the Pomo pit model,
(iii) investigate the sensitivity of the model to different data sets,
(iv) examine uncertainty in the model results using MCMC approaches.

2. European hake, *Merluccius merluccius*, in GSA 17

A stock assessment of European hake, *Merluccius merluccius*, was undertaken using a length based model with the CASAL software. European hake is distributed throughout the Adriatic Sea, with the exception of a small area northern of the Po river (Ungaro et al., 1993; Jukić et al., 1999). The most abundant population is located at depth between 100 and 200 m, specifically in the area of the Pomo/Jabuka pits, where catches are mainly composed of juveniles (Jukić and Arneri, 1984; Županović and Jardas, 1989; Vrgoč, 2000). This area is considered a nursery ground for this species, whereas spawning area were identified in the eastern part of the Adriatic Sea (Mediterranean Sensitive Habitats, 2013).

Hake model was developed considering the GSA 17 as one area, notwithstanding Italian and Croatian fisheries were taken in account separately. Based on hake biological features, sex was considered combined and different von Bertalanffy parameters were tested for comparing slow and fast growth. Spawn occurs throughout the year, with two peaks: one in summer and one in winter (Karlovac, 1965; Jukić and Piccinetti, 1981; Ungaro et al., 1993). These features suggested to develop the model considering three time steps: time step 1, in which recruitment occurs and corresponding to the beginning of the year; time step 2, represented the central months and in which fishery, spawning and natural mortality occur; time step 3, in which only growth occurs and corresponding to the end of the year and.

Preliminary length based assessment model for European hake (*Merluccius merluccius*) in GSA17

Considering the data available, the model to assess hake was developed from 1982 to 2014. Owing to the difficulties associated with ageing of hake in the Mediterranean, the model was length-based. Fishery data were organized by country, specifically for the Italian side only bottom trawlers (OTB) were considered, whereas for the Croatian side long liners (LLS) were also taken into account. Two sources of survey information were available: GRUND and MEDITS. The GRUND survey started in 1982 and finished in 2007, at the beginning Italy was the country mainly involved in this survey and the sampling scheme was organized doing four repetitions per year (spring, summer, autumn and winter); however the longest time series is represented by the GRUND survey occurring in autumn. Croatia was involved in the GRUND survey only in the most recent years, from 2002 to 2005 and 2007. GRUND indexes were grouped in two surveys, one including both Italy and Croatia, GRUND ALL, and the other one including only Italy, GRUND ITA. MEDITS survey is a spring/summer survey started in 1994 and still ongoing; the time series included in this assessment goes from 1996 to 2013, since for these years both Italy and Croatia participated at the survey. MEDITS survey 2014 wasn't taken in account as data were collected in different months (August to November) compared to the previous years. For year 1999 no survey data are available. Data used in this assessment are listed in Table 6.

Also for hake, natural mortality was applied as a vector by length, calculated with PRODBIOM (Abella et al., 1997).

Selectivity was modelled as double normal, with different peaks for each survey and fishery.

Table 6. Data available for hake assessment.

Landings	1982 - 2014
Length frequency of commercial catches	OTB ITA (2006-2014) OTB CRO (2008-2014) LLS CRO (2006)
Surveys	GRUND ITA (1982; 1985; 1988; 1991; 1992-2001; 2006) GRUND ALL (1984; 2002-2005; 2007) MEDITS (1996-2013)
Length frequency of survey catches	GRUND ITA and ALL (1982; 1984; 1985; 1988; 1992-2007) MEDITS (1996-2013)
Growth	Fast growth (EWG 13-05); slow growth (Alegria Hernandez and Jukić, 1990); Medium growth (Vrgoč, 2000)
Maturity	Vrgoč et al., 2004
Length weight relationship	EWG 13-05
Natural mortality	Calculated with PRODBIOM (Abella et al., 1997)

Final preliminary model

First the model was developed considering the fast growth parameters, that are internationally accepted for the growth of hake but still under discussion for the Adriatic Sea, where bigger sizes (and ages) are poorly represented. The use of these parameters resulted in unbelievable estimates that suggested to try other sets of parameters describing a slower growth. Thus, the model was also run using slow growth parameters (Alegria Hernandez and Jukić, 1990) and a set of parameters describing an intermediate growth (Vrgoč, 2000). This last set of parameters seemed to work better given the available data; the following results refer to the run developed with these values.

Fits of the model are represented in Figure 19. Then, B0 was calculated and it was equal to 26340 tonnes, with a total stock biomass of 10829 tonnes in 2014, representing 41% of B0 (Fig. 20). The model estimated an increasing trend to 1992 (34721 tonnes), followed by a continuous decreasing trend to 2013 (10201 tonnes), with a weak increment in the last year (10829 tonnes). Peaks of recruitment were detected in the first years and around the early 1990s, after that recruitment accounted for small values.

Selectivity shows the expected patterns (Fig. 21), describing a higher preference of smaller individuals in the Croatian trawlers and the MEDITS survey, instead bigger sizes are selected by Croatian long liners only. Average fits to the length distributions are quite good (Fig. 22), differences reflect the variability inside individuals samples.

Annual fishing mortality (F_{bar}) was estimated as a mean annual value of the most fished length classes (10 – 40 cm), and it shows a continuous increasing trend to 2012 (F_{bar} = 0.5) followed by a weak decrease.

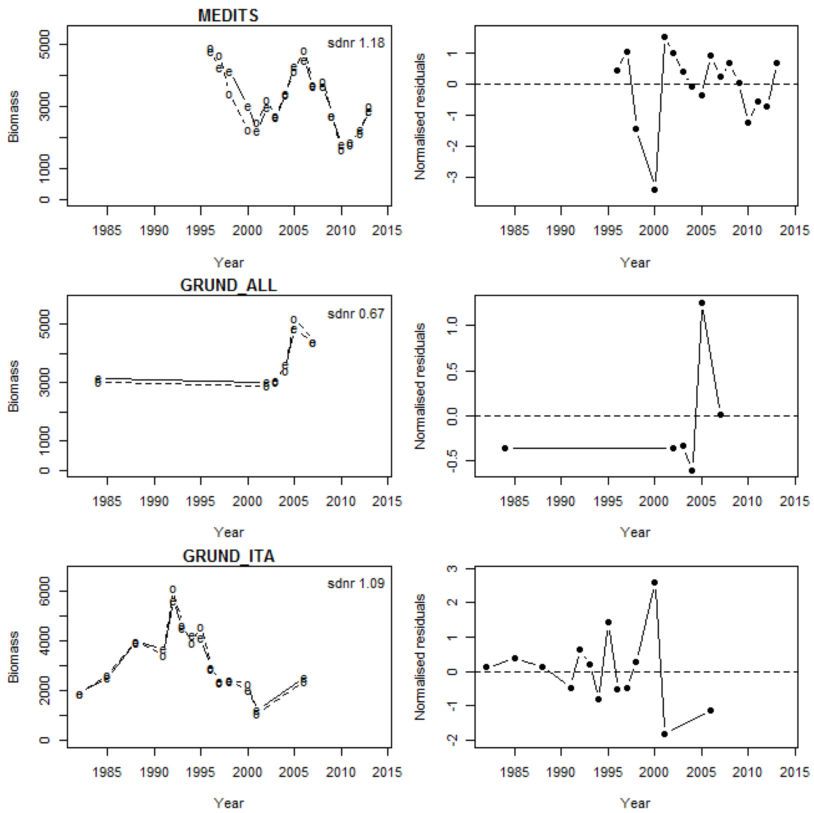

Figure 19: Fits to trawl survey indices (left column) and normalised residuals (right columns) for each survey

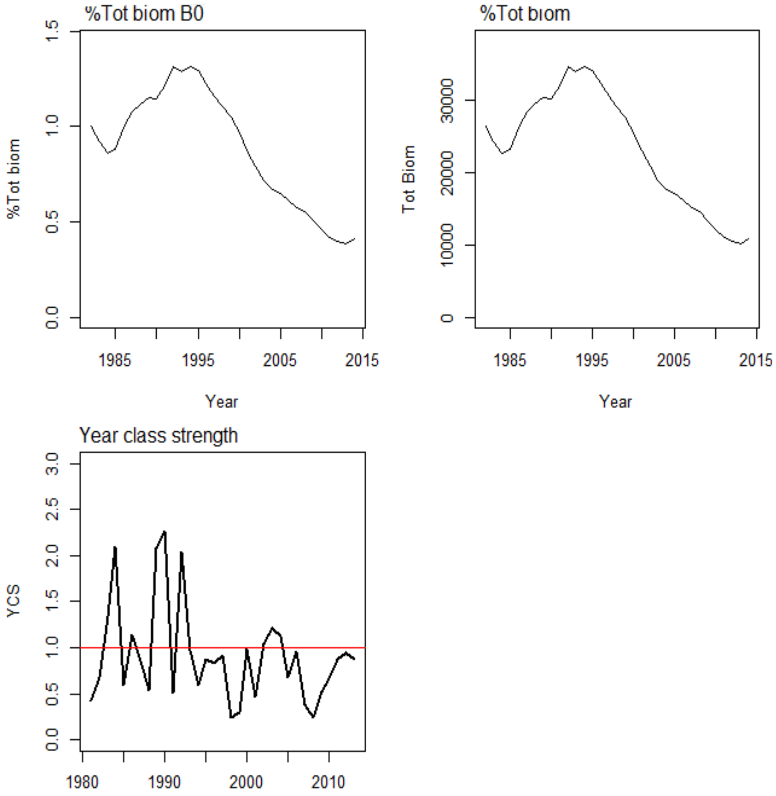

Figure 20: Trajectory of total biomass as a percentage of B0 (top left), estimated total stock biomass (top right), year class strength (YCS) (bottom left).

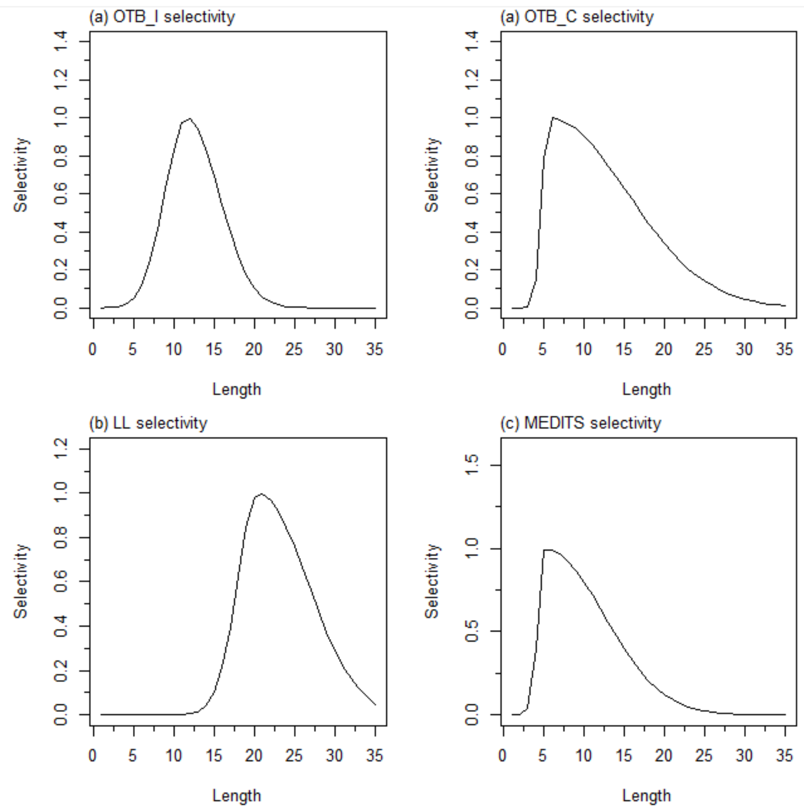

Figure 21: Estimated selectivity pattern for each fishery and survey.

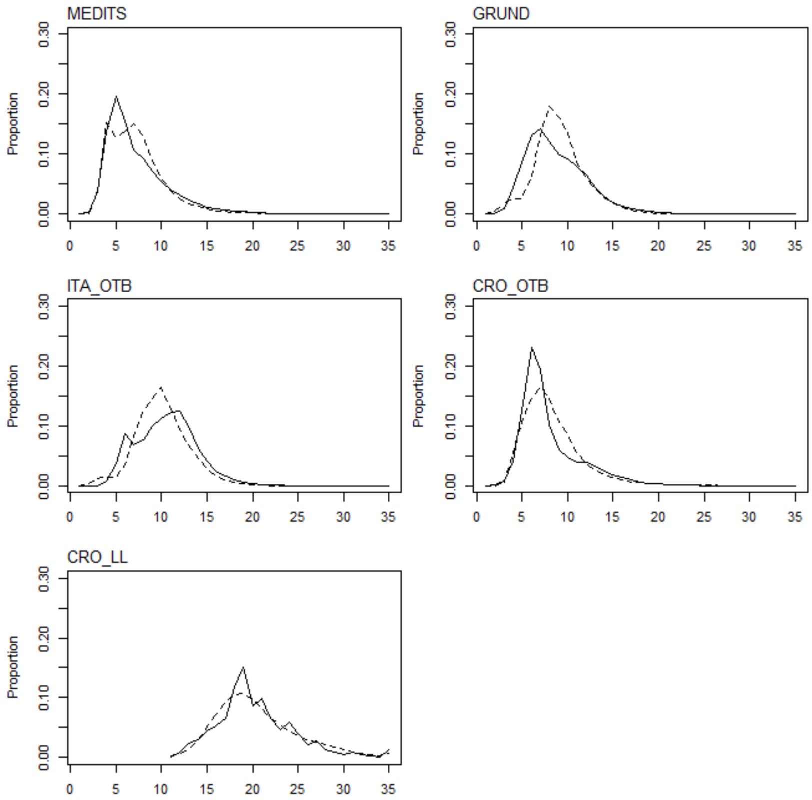

Figure 22: Fishery and survey selectivity curves. Solid line – observed data; dotted line – estimated data.

Figure 23. Plot of estimated F_{bar} (10 – 40 cm) over the modelled period 1982 to 2013, for the whole stock

Next step

Model can be improved estimating an F_{bar} value for each fleet. Then, parameterisation of the model can be improved applying a likelihood profile and uncertainty can be examined using an MCMC approach.

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