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Report of the Workshop on stakeholder input to, and parameterization of, ecosystem and foodweb models in the Irish Sea aimed at a holistic approach to the management of the main fish stocks (WKIrish4)

23–27 October 2017

Dún Laoghaire, Ireland

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Executive summary

The Workshop on stakeholder input to and parameterization of, ecosystem and food-web models in the Irish Sea aimed at a holistic approach to the management of the main fish stocks (WKIrish4), chaired by David Reid and Francis O'Donnell (Ireland), was held in Dún Laoghaire, Ireland, 23–27 October 2017.

The workshop was divided into four main components:

- Identifying stakeholder concerns with respect to ecosystem impacts on fisheries;
- Provide stakeholder inputs on predator prey interactions among key species and evaluate foodwebs from this;
- Reconstruction of effort trajectories for the main gears used back to 1973;
- Parameterise fishing components for an ODEMM IEA for the Irish Sea.

Stakeholder concerns under ToR a, focused on the patterns of movement between the Irish Sea herring stock and those in adjacent waters, particularly the Celtic Sea, and the west of Scotland. They also raised similar questions about whiting, cod and haddock, and the approaches identified would be applicable to these stocks as well.

The models systems used within WKIrish (Ecopath with Ecosim, and Le Mans ensemble modelling) are not able to estimate migrations, but can use migration information. The focus was then moved to how to gain that information. A range of possible approaches to gathering information on the movements of herring into and out of the Irish Sea were discussed. These included; genetics, otoliths, morphometrics, tagging, vertebral counts and parasite markers. These issues were also examined by WKSIDAC in 2017. The conclusions of both workshops was that genetic tools held the greatest potential and were the most cost-effective approach.

The second component of the workshop was to tap stakeholder knowledge to provide information on predator–prey linkages in the Irish Sea in 1973, and effort trajectories by gear back to 1973. This year is the base year for both models, and forward projections made from that date. This work encompassed the second and third ToRs for the workshop.

In terms of the predator–prey interactions, the focus was on the key commercial species, those observed most regularly by stakeholders. Information from the Cefas stomach content/diet database was also available. Modified foodwebs based on both sources were developed and have been applied in both models.

Effort time-series data for the main gear types used in the Irish Sea are available back to 2003 from the STECF database. However, as the models use 1973 as a key year, the need for effort data from 1973–2003 was identified. We used the STECF data as a starting point, and then working with stakeholders, the likely trajectories back from this point, 2003–1973. Essentially stakeholders were asked if the effort (considered as fishing power) would have increased or decreased prior to 2003, and in which years and at what scale. These data could then be plugged into the models, and projections forward from 1973 made on this basis. Initial analysis with the trajectories in the EwE model suggested that that the scale of changes described by stakeholders were too great for the model to work properly. We then utilised some simple standardisation

routines, as used in meteorology, and reran the models this time successfully. This retained the trends in the stakeholder perceptions but reduced the scale of change in them.

The combination of new comprehensive effort trends and foodweb interactions have now been incorporated into the models, and these are now able to predict the stock trends with some accuracy. Although work is still preliminary, indications are that the changes in the stocks in the Irish Sea are likely driven by changes in fishing pressure AND in broader ecosystem drivers, notably the NAO (possibly through primary productivity), and temperature changes. Temperature has increased substantially in the Irish Sea since 1973.

It should be emphasised that these findings are preliminary, and may change as the models are refined. However, the performance of the models and the conclusion from these look promising.

The final element of the workshop was to work with the stakeholders to populate an ODEMM IEA assessment for the Irish Sea using differentiated fishing gears. Previous approaches had treated fishing as a single sector, the aim here was to take this to specific gear types; Beam trawl, Otter trawl, pelagic trawl, pots and dredges. Stakeholders were asked how each gear impacted the environment in terms of pressures, and then the ecosystem components impacted. The ODEMM analysis was then updated and the results fed back to the stakeholders.

In conclusion, the workshop was a wonderful exercise in stakeholders and scientists working together to solve problems, and it was enjoyed by all concerned.

1 Opening of the meeting

The Workshop on stakeholder input to and parameterization of, ecosystem and food-web models in the Irish Sea aimed at a holistic approach to the management of the main fish stocks (WKIrish4), chaired by David Reid, and Francis O'Donnell (Ireland), was held in Dún Laoghaire, Ireland, 23–27 October 2017.

The workshop was set up as a follow-up to the scoping workshop on the impact of ecosystem and environmental drivers on Irish Sea fisheries management (WKIrish1), held in Dublin, Ireland, in September 2015. That workshop identified a number of approaches that could be used to evaluate ecosystem/fisheries linkages in the Irish Sea. In particular, the development of a tailored Ecopath with Ecosim (EwE) model, Multi-species fish community modelling, and Integrated Ecosystem Assessment (ODEMM) were highlighted. In all three cases it was agreed that there was considerable value in using stakeholders' knowledge to both parameterize, and to help set the main objectives for the modelling. In particular, for specification of the foodweb linkages, and for the key human activities, pressures, and ecosystem components for consideration.

As part of the WKIrish regional benchmark process, WKIrish4 built on the conclusions and recommendations of the Scoping Workshop (WKIrish1), the Data Evaluation Workshop (WKIrish2), and the Stock Assessment Workshop for Irish Sea stocks (WKIrish3) to:

a) Identify and document the main ecosystem concerns for stakeholders and determine if these can be addressed with the available models, and make any appropriate recommendations for future work;

b) Populate an Irish Sea foodweb structure based on stakeholder perceptions;

c) Evaluate the out-turn foodweb structures against those developed by scientists;

d) Specify appropriate human activity sectors, pressures derived from these and ecosystem components appropriate to an ODEMM IEA for the Irish Sea.

WKIrish4 will report by 1st December 2017 for the attention of ACOM and SCICOM, as well as for any proposed WKIrish5.

2 Identify and document the main ecosystem concerns for stakeholders (addressing ToR a)

Based on a request by the NWWAC, the workshop reviewed stakeholder ecosystem issues, and where possible identified how these could be addressed *inter alia* using the ecosystem models.

The main topic raised by the stakeholders was the issue of the movements of herring between the managed stocks in west of Scotland (6.a(S)), the Irish Sea 7.a) and the Celtic Sea (7.a South of 52° 30′ N and 7.g,h,j). Similar concerns were raised with reference to cod, haddock and whiting, but the main current issue would be for herring.

In the context of the models being developed for the Irish Sea within WKIrish, it was agreed that these were not the appropriate tools to elucidate this issue. Both model types basically assume that the Irish Sea represents an enclosed or independent ecosystem. Migration into and out of the area can be included, but this would need information on the likely migrations of the stock of interest. Were this available, then the models could describe the impact on the stocks, and other functional groups, but could not determine the migrations themselves. For this reason, the workshop then focused on how best to obtain such information.

2.1 Migrations and abundance distributions of herring in the Irish Sea and adjacent waters

2.1.1 Mixing of Celtic Sea herring in the Irish Sea: overview

It is well known that herring aggregations around the Isle of Man at spawning time include fish that will eventually migrate to the Celtic Sea to spawn. The last tagging study showed that of herring found at spawning time in the Isle of Man, about 50% were Celtic Sea fish (ICES, 1994; Molloy *et al*., 1993; Figure 1). Only 40% were native Manx fish, the remainder being Mourne component. The new Irish Sea benchmark treats all the herring around the Isle of Man as being Irish Sea herring. But also, it treats the acoustic estimate, from the Northern Ireland survey, as being an absolute one, not a relative index as is done in all other stock assessments in ICES.

The occurrence of juvenile Celtic Sea herring at Irish Sea nursery grounds has long been acknowledged (Bowers, 1964; Molloy and Corten, 1975; Molloy, 1980). This was further underlined by otolith work by Brophy and Danilowicz (2002), Brophy *et al*. (2006), Burke *et al*. (2008a,b) and Beggs *et al*. (2007) who also found juvenile Celtic Sea herring on the spawning grounds at the Isle of Man (Figure 2).

Brophy and her co-workers did not find adult Celtic Sea fish in the Manx spawning grounds. This is at odds with the findings of Molloy *et al*. (1993) whose study included adult herring. However, Brophy's work was based on sampling in 1999 and 2000 when the Celtic Sea stock was very low, and its age structure severely attenuated. On the other hand, Molloy's sampling was in 1991 when the Celtic Sea stock was healthy with lots of older fish present. Thus, the abundance of Celtic Sea herring adults could have been too low to have been detected in Brophy's sampling.

Subsequent otolith microstructure work conducted by AFBI by Beggs *et al*. (2008) confirmed the presence of adult Celtic Sea herring in the Manx spawning grounds (Figure 3), agreeing with Molloy *et al*. (1993). Beggs *et al*. concluded that there was significant mixing of Celtic Sea fish in the Northern Ireland survey, that biomass overestimate the Manx stock size and that catches data are also likely to contain "winter" type fish.

By treating the Irish Sea herring spawning biomass survey as an absolute stock index there is risk of an upward bias in the 7.aN herring assessment. This could lead to F being set too high for individual components. The results of SGHERWAY (ICES, 2010) show that individual components that mix with each other, can be managed sustainably if individual component target F on each is set at ~F_{MSY} levels, all stocks are above safe biological limits, and contamination of survey indices (through mixing) is modest. SGHERWAY further showed that managing metapopulations is only possible with detailed information on fisheries-independent data. However, whenever subcomponents of the metapopulation differ considerably in abundance, sustainable management is impossible for the smaller or smallest subcomponent(s). Furthermore Hintzen *et al.* (2015) conclude that when dealing with population components of very different relative size, misclassification of individual components in surveys can be a problem. In combination with classification error, the smaller population unit survey index becomes a reflection of the larger unit densities rather than a poorly sampled composition of the population unit itself. Managing on such a basis might pose problems if the development of individual population units is not in synchrony, which could lead to overexploitation, the loss of spawning units, and therefore also resilience of the population complex (Smedbol and Stephenson, 2001).

The ICES advice for Irish Sea herring for 2018 is a partial metapopulation advice. That is to say, it provides advice for all stocks present in the Irish Sea. This is a paradigm shift, because in previous years the advice for Irish Sea herring was only for the native stock, and not immigrant or emigrant stocks. The main stock present in the Irish Sea, apart from the native stock, is the Celtic Sea herring. The advice for this stock continues to be at a stock level. There is a discontinuity in how advice is given of the Irish-Celtic Sea herring metapopulation across its range.

2.2 Possible research avenues

A number of possible stock discrimination approaches were considered by WKSIDAC (ICES, 2017). These included, most obviously, genetic methods, but also otoliths, vertebral counts, morphometrics, and parasite markers. For the Irish Sea, and for discrimination in stocks with the West of Scotland, and the Celtic Sea WKSIDAC recommended a combined approach. A genetic multi-marker approach in combination with morphometrics and otolith shape analysis have been used to characterise the spawning stock baselines. WKSIDAC envisaged that only genetic methods of discrimination would be used in future.

Other approaches were also raised at the workshop. Vertebral counting has been carried out on herring stocks in Irish waters (Molloy, 1980; Molloy and Corten, 1975), and has also been used to some success in the Baltic and North Sea (Berg *et al.*, 2017). Parasite markers were also used with some success in the WESTHER project (Campbell *et al.*, 2007). Morphometrics were also a potential approach, and had some success in the West of Scotland herring populations (ICES, 2015); however WKSIDAC concluded that it was too labour intensive for routine use.

Otolith studies offer a number of possible avenues, including; morphometrics, internal structure, and microchemistry. Morphometric approaches were examined in detail by WKSIDAC, but no conclusions were drawn. Otolith microstructure has also been widely used and can be successful in discriminating spring and autumn winter spawners in the North Sea and western Baltic (Clausen *et al.*, 2007). However, WKSIDAC concluded that the individual skill and experience, and potential for errors did not support using this approach. Otolith microchemistry, where fish with different origins can have different isotope signatures in their inner otoliths may have potential and has been explored by Nash *et al*. (2015), but is in an early stage of development. Unlike genetics, the method does not provide information about stock origin, it provides information about where a fish was at a particular point in its life. Carbon[14] has also been used as a marker for fish hatched in the Irish Sea influenced by Sellafield nuclear power plant (Heymans, pers. comm.), and may also have potential.

Tagging was also raised in the workshop as a possible tool. This was used with considerable success in the 1990s, and indicated mixing between Irish and Celtic Sea stocks (Molloy *et al*., 1993).

In conclusion, although many approaches to stock ID are possible, the most promising by far would be the use of modern high definition genetic methods that are likely to be accurate and cost-effective.

The genetic approaches are reviewed in detail in a Working Document "Background information on the genetics work undertaken on western herring stocks" developed by Edward D. Farrell, School of Biology and Environmental Science, University College Dublin, Ireland. The location of existing genetic samples is presented in Figure 2.1.

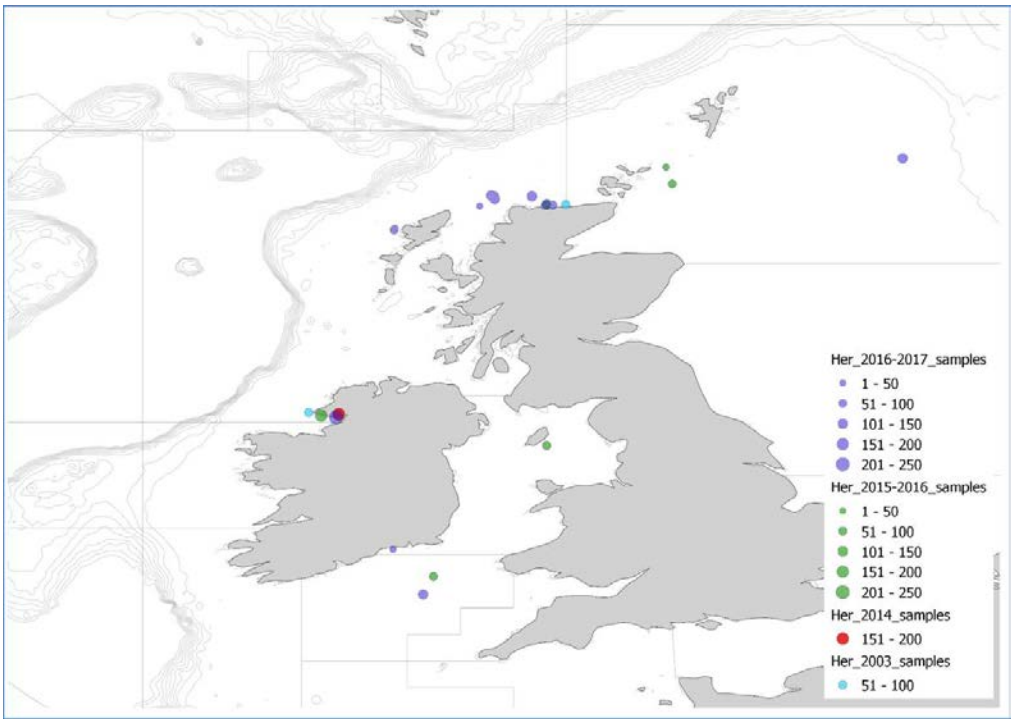

Figure 2.1. Baseline spawning herring samples collected 2014–2017. Locations of the 2003 WESTHER samples are also indicated.

3 Populating an Irish Sea foodweb structure based on stakeholder perceptions (addressing ToR b)

The aim of this part of the workshop was to draw on stakeholders' experience and knowledge to describe the key elements of the foodweb in the Irish Sea as it would have been in 1973. This year was the base year for the two models. While stomach and diet data were available from Cefas stomach database REFREF, in this exercise we based the approach on tacit knowledge from many years fishing experience in the area and back to 1973. The focus was principally on the predator/prey interactions for the main commercial species. Non-commercial species were involved principally only as either predator or prey for these commercial species.

3.1 Consensus predator–prey assessments

The approach taken at the workshop was to work in a single group, with a flip-chart to record responses. The stakeholders were asked about each key commercial species that they had actually fished on, and as far back as possible in time, ideally to 1973. Each species was considered in turn. Figure 3.1 shows the workshop underway, not the relaxed environment.

Figure 3.1. The foodweb component of the workshop underway.

Where possible, the stakeholders were asked about both juvenile and adult fish, as these were represented as two separate stanza in the EwE modelling. An example of a completed appraisal, in this case for cod in the 1970s and 1980s, is presented in Figure 3.2.

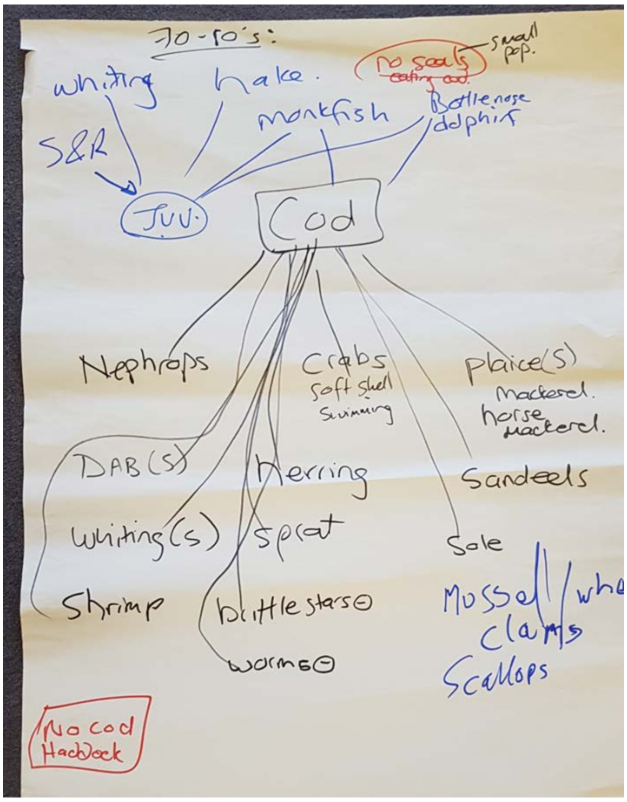

Figure 3.2. Foodweb links for adult (centre) and juvenile cod (left of centre). Please note that not all of the individual species were finally represented in the complete foodweb as their own functional groups.

The information was then recorded in a more formal context, and can be summarised more clearly in Figure 3.3, again for cod. The degree to which cod predated on, or was prey for, the other species is represented by the size of the arrows. This information was also elicited at the workshop.

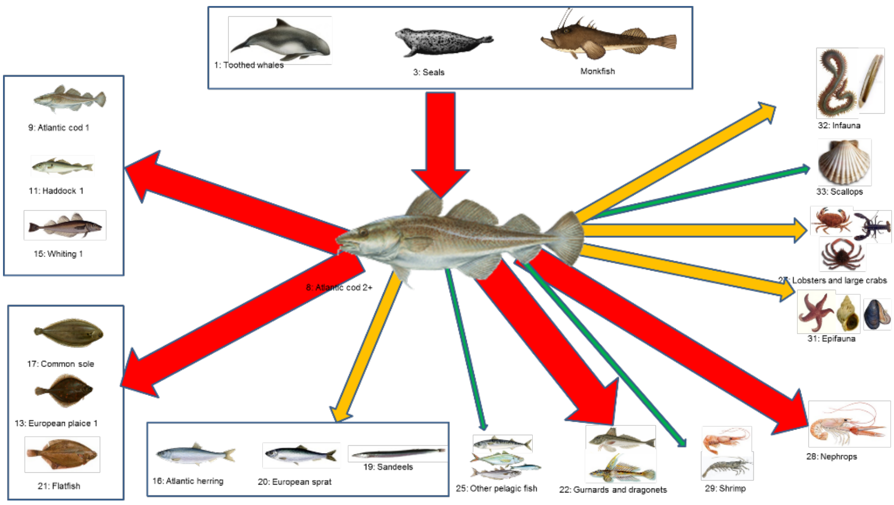

Figure 3.3. Foodweb linkages from the stakeholder exercise for adult Irish Sea cod. The size of the arrows represent the scale of the interaction, and their direction showing whether they were considered as prey or predator.

Similar exercises were carried out for haddock, whiting, plaice, *Nephrops* and the commonly caught species of skate and ray. The choice of species was based on the fish commonly encountered by the fishers in their operations, and where they would actually have seen gut contents while processing the catch. Not surprisingly, these diet matrices differ to some degree from those developed from the Cefas stomach database. This will be in part due to the request for diet data for the 1970s, and 1980s, and that the foodweb, and species dominance may have changed since then. It may also reflect a genuine difference in the diets. The two data sources will be used in the EwE and Monte Carlo analyses together, and also with consideration of where the diets can be seen as different from each other. Figure 4.4 shows the original foodweb from the Cefas stomach database, and the components derived from the stakeholder exercise.

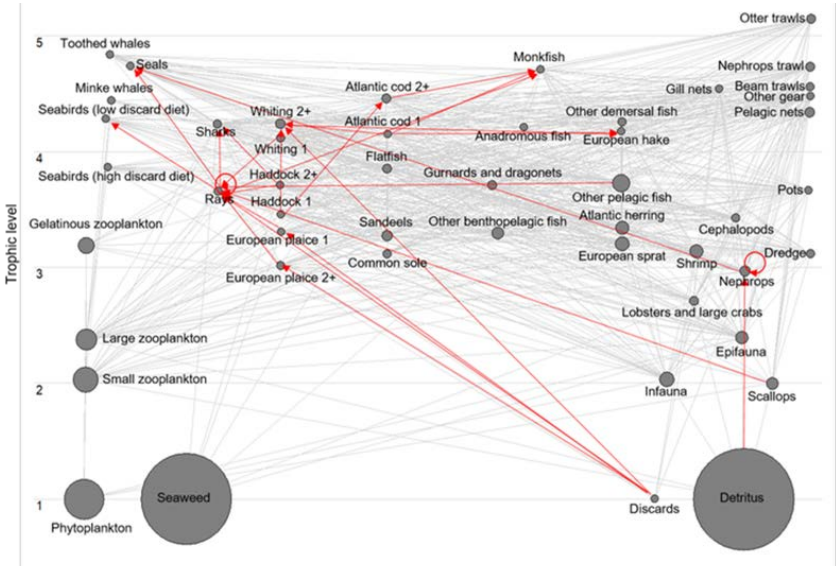

Figure 3.4. Foodweb from Cefas stomach data (in grey), and the linkages identified by stakeholders (in red).

4 Effort trajectories by gear for the Irish Sea back to 1973 (addressing ToR b)

The aim of this part of the workshop was to draw on stakeholders experience and knowledge to describe the change in effort for all the different gears from 1973 to date. This work was needed as while there are some data for the time-series available, they do not go back to 1973. The STECF data are only available from 2003 to date. Catch data can be used as a proxy for effort, with some caution; however, the aim here was to derive new effort series based on the experience of the stakeholders present at the workshop. The approach taken was to work with the stakeholders using graphical representations of the known effort time-series from the STECF data (see the black line in the example for TR1 vessels in Figure 4.1.). Using these data as a baseline, stakeholders were then asked how the effort had evolved back from that time: increased, decreased, by how much, to which years, etc. The resulting trajectory is shown in Figure 4.1 as the red line.

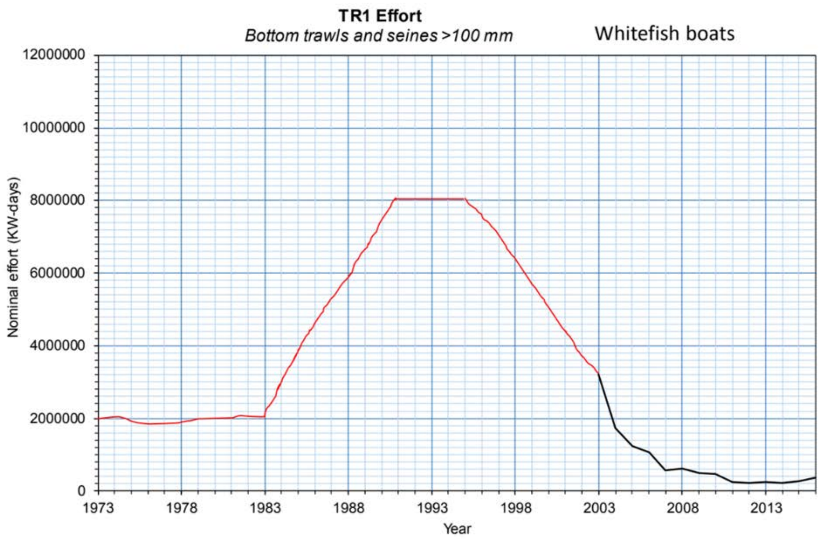

Figure 4.1. Effort trajectory reconstruction for TR1 vessels in the Irish Sea. The black line represents the STECF dataseries, and the red line represents the stakeholder reconstruction from 1973–2003.

Following this, we explored the introduction of the time-series for a range of gears into the EwE model. Initial runs suggested that the scale of the changes reported by stakeholders was too great for the model, and led to extinction of some species. We therefore standardised the anomalies by dividing them by their standard deviations, a method used to normalise trends in climatology. With this standardisation the model runs worked well and we were able to retain the trends. This did, however, mean that the magnitude of change was similar across all fishing effort by gear (i.e. they all tended to peak around three to four times their initial relative fishing effort).

The effort trends before and after standardisation and for all gears is shown in Figure 4.2 a and b.

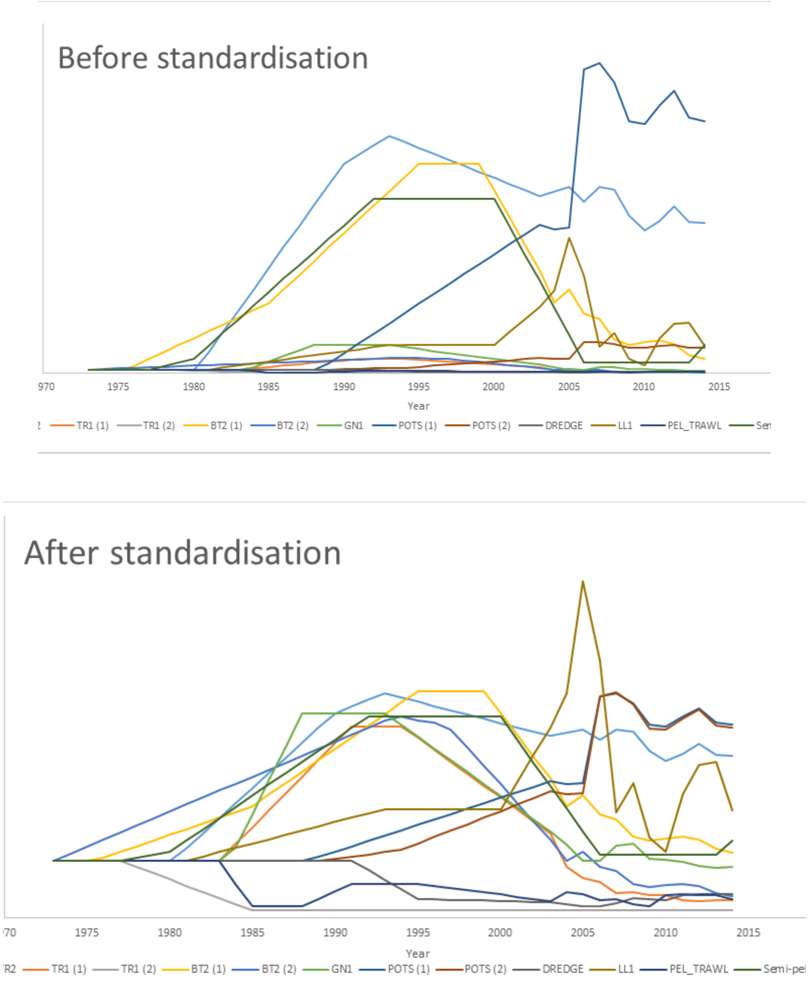

Figure 4.2. Reconstructed effort trends by gear before standardisation (a. top panel) and after (b. bottom panel).

We plan to run will multiple effort series through the model, retaining the trend but altering its magnitude, to find which magnitude produces the best statistical fit. Figure 4.3 illustrates the initial fishers effort with +/- 90% uncertainty applied to the magnitude of change relative to effort in 1973. Multiple trends within the +/-90% range will be used to drive the model, identifying the magnitude(s) most capable of increasing the models statistical fit to observed data.

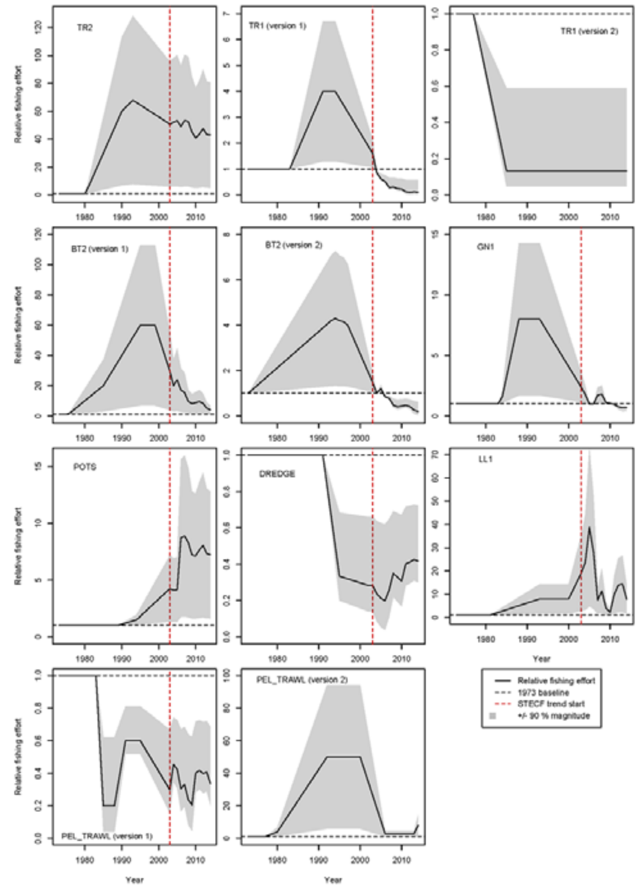

Figure 4.3. Initial fishers' effort reconstructions with +/-90% uncertainty applied to the magnitude of change relative to effort in 1973.

5 Initial outputs from the EwE modelling (addressing ToR c)

Preliminary runs of the EwE model using most of the data were carried out, and some of the results are presented here. It should be emphasised that these are very preliminary calculations, and that further work will required.

The plots in Figure 5.1 show the EwE models capacity to replicate the biomass trends of commercially exploited stocks in the Irish Sea (Cod 2+; Whiting 2+; Haddock 2+; European plaice 2+; Sole; Atlantic herring; *Nephrops*) from 1973–2014. This model has been fitted against biomass (blue points) and catch time-series using fishing effort and fishing mortality data from ICES. The figures show multiple trend lines for each stock, representing different stages of the fitting procedure:

Black dashed line: model predictions prior to Monte Carlo (MC) analysis and formal fitting. The dynamics of the stocks in this instance are being driven by fishing and temperature. The sum of squares (SS) is 2852.

Red dashed line: model predictions post MC. The MC routine (1000 model iterations) was used to alter basic input parameters (biomass, production/biomass and consumption/biomass) based on data pedigree (how much we trust the data/known potential ranges for input data). The model is still only being driven by fishing and temperature, however the input parameters have been 'optimised'. The 5% and 95% quantiles from the MC procedure are included in the figures as grey shaded areas. The SS is 2493.

Thick red line: model predictions post formal fitting (using the MC altered model). 49 validation time-series (biomass and catch) were used in the model, allowing us to estimate a maximum of 48 parameters (if we are maintain statistical integrity). After running an automated fitting procedure, the best model (lowest AICc) estimated 35 vulnerabilities (top–down/bottom–up trophic interactions) and a primary production anomaly with three spline points (resembling the inverse of the NAO). The model, after MC optimisation, is now being driven by fishing, temperature, vulnerabilities and a primary production anomaly. The SS is 1223.

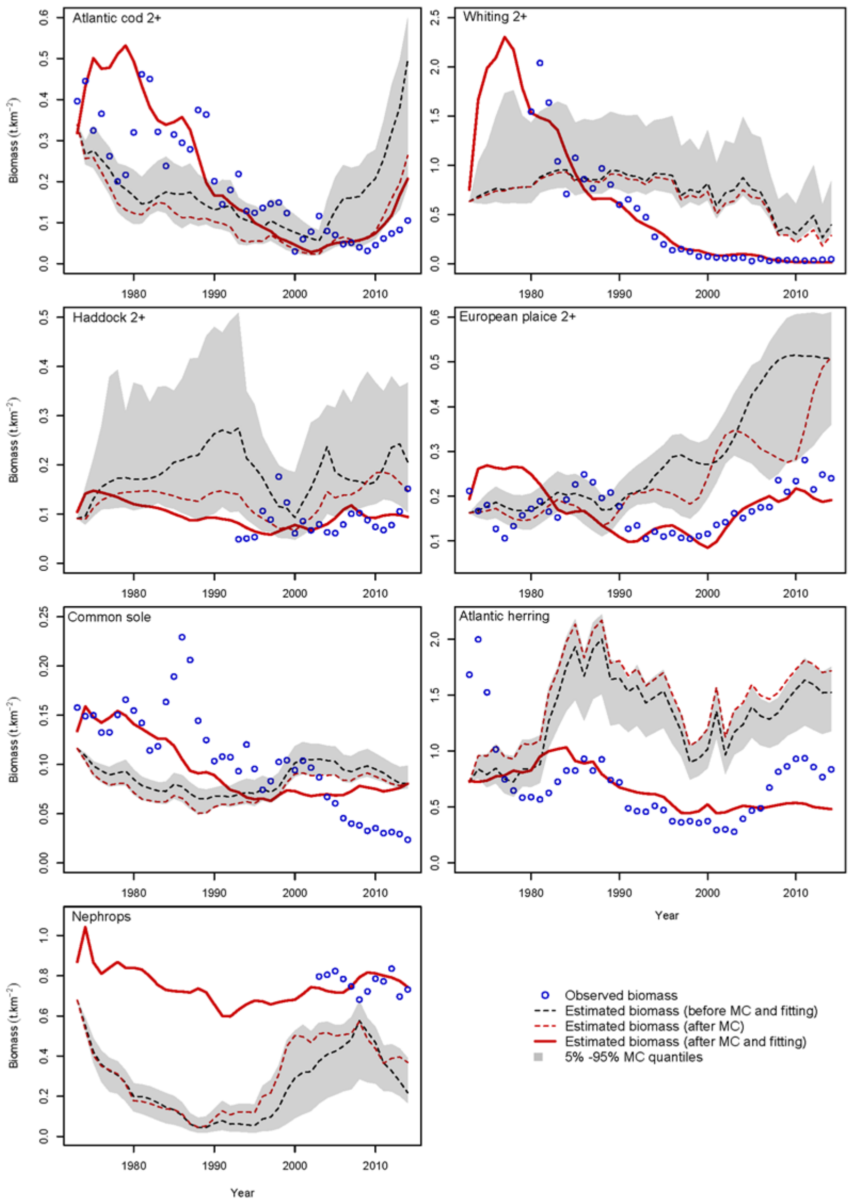

Figure 5.1. Time-series for observed and modelled stock trajectories for a number of key functional groups.

Figure 5.2 illustrates the novel approach taken towards assessing the uncertainty inherent in Ecopath diet matrices, as well as highlighting the importance of using stakeholder information during model conception. In this instance, we have taken an Irish Sea foodweb built using scientific data only (blue) and a foodweb which uses scientific data and fishers knowledge (red). Using linear network analysis we applied a 25% uncertainty range around every trophic interaction (energy flow) and generated 10 000 plausible network configurations for both foodwebs. To assess the difference between foodwebs we employed Ecological Network Analysis (ENA) to explore the ENA indicators often used to characterise ecosystems. The figure presented here shows a probability density plot and boxplot focuses on the distribution of Finn's cycling index (FCI) in the Irish Sea, with and without fishers knowledge. FCI represents the fraction of material recycled in a system and is often correlated with system maturity. The fact that we're seeing higher FCI values when using fishers' data, is likely due to their increased knowledge of discard consumption which is not directly picked up in the data.

This figure largely illustrates a ‘proof of concept’. It is our aim to assign uncertainty to each trophic interaction based on actual data (where available) in place of the uniform 25% uncertainty.

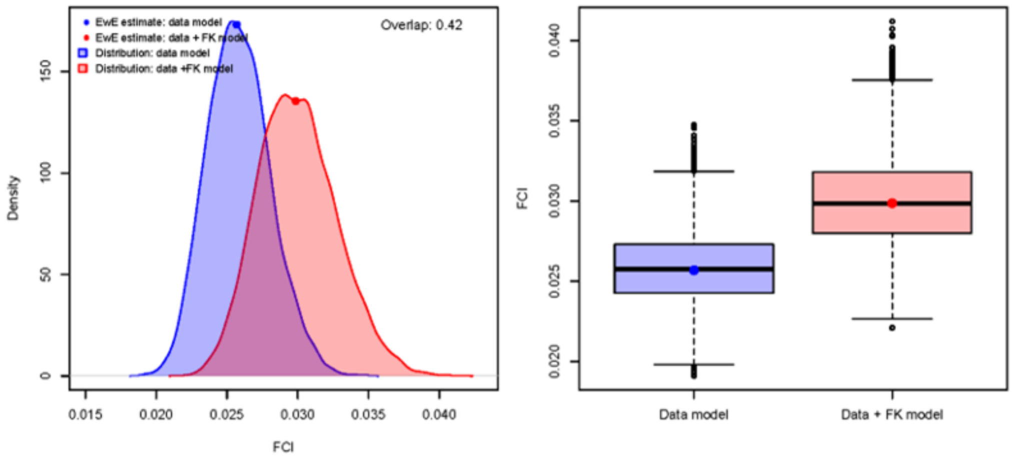

Figure 5.2. Finns Cycling Index with and without incorporating fishers information.

Figure 5.3 shows the mixed trophic impact plot, assessing the impact that changes in the biomass of any one group will have on other groups in the system.

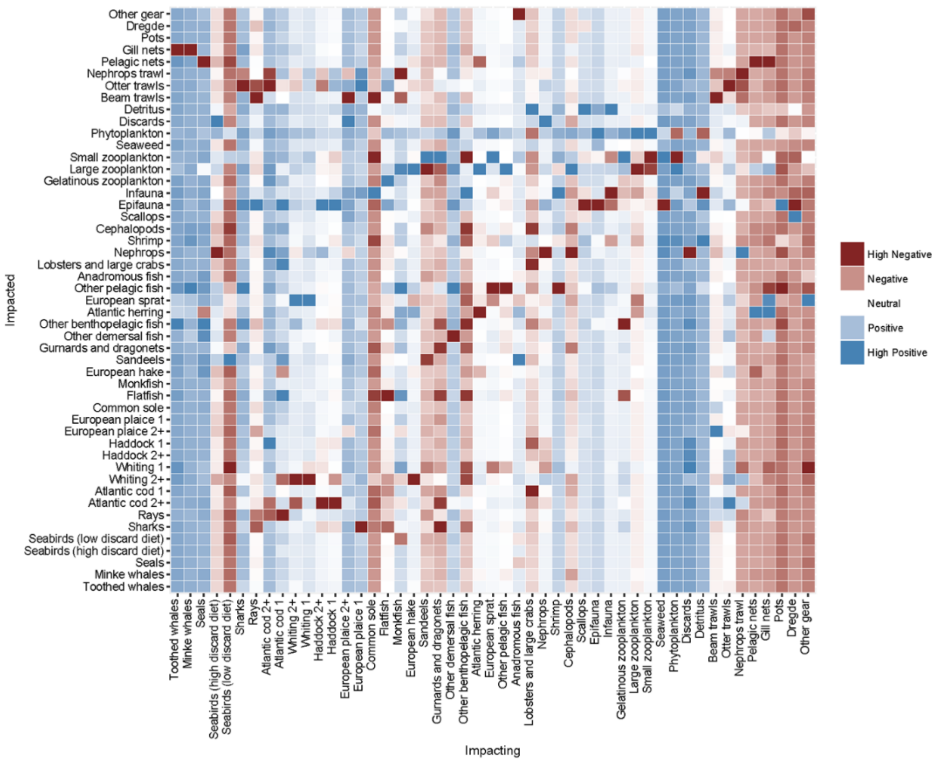

Figure 5.3. Mixed trophic impact plot.

The depth integrated temperature trends for the Irish Sea were constructed using annual averages from 11 depth layers. Figure 5.4 shows the average spatial temperature at 11 depth layers, extracted from the Atlantic-European North West Shelf-Ocean Physics Reanalysis from Met Office (1985–2014). The reanalysis covers the period January 1985 until July 2014 and is based upon the Forecasting Ocean Assimilation Model 7km Atlantic Margin Model (FOAM AMM7).This is a hydrodynamic model of the Northwest European shelf forced at the surface by ERA-interim winds, atmospheric temperature, and precipitation fluxes.

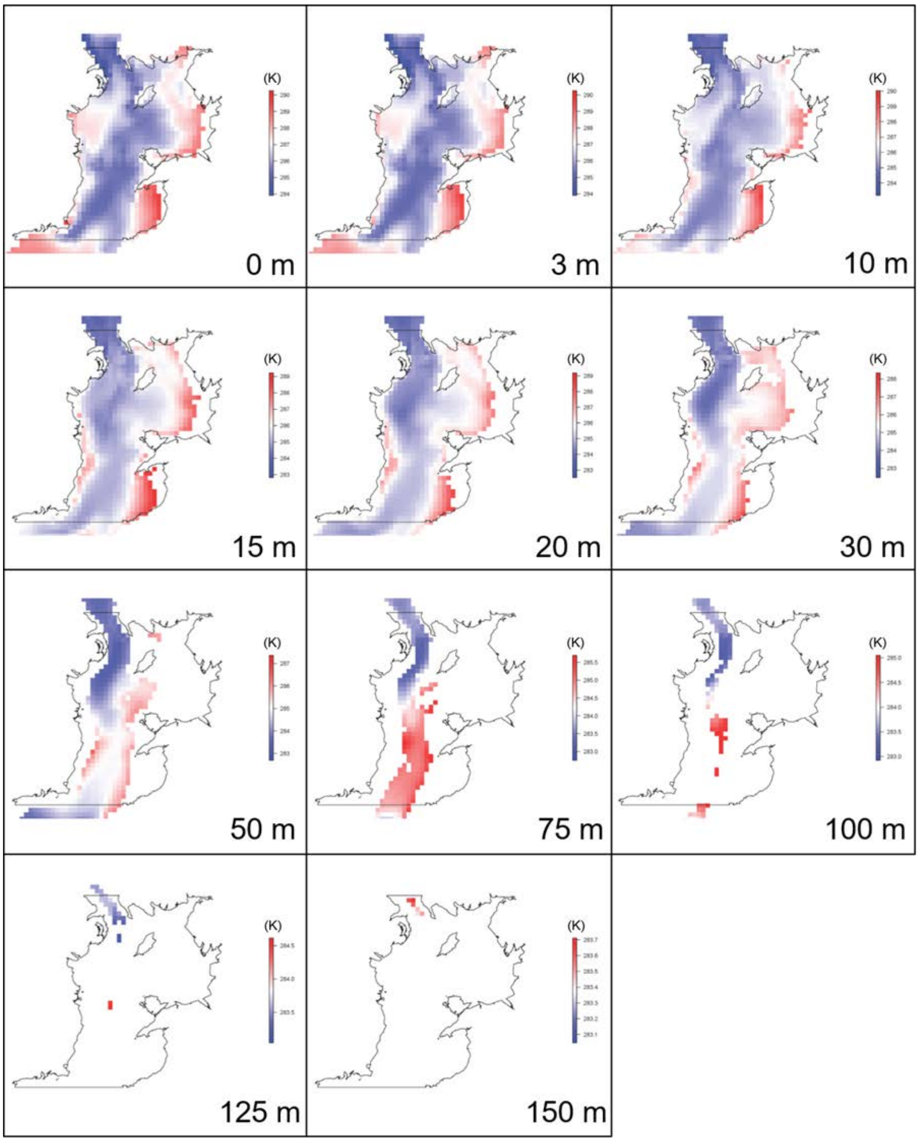

Figure 5.4 Average spatial temperature at 11 depth layers, extracted from the Atlantic-European North West Shelf-Ocean Physics Reanalysis from Met Office (1985–2014).

Figure 5.5 shows the depth integrated temperature of the Irish Sea from 1973–2014. Three trends were calculated and applied to species according to their ecology and preferred depth in the water column. Depth integrated data from the Met Office span 1985–2013 only. Temperatures from 1973–1984 and 2014 were calculated using the Hadley Centre Sea Ice and Sea Surface Temperature dataset (ISST) (1973:2014) based on its empirical relationship with the Met Office data

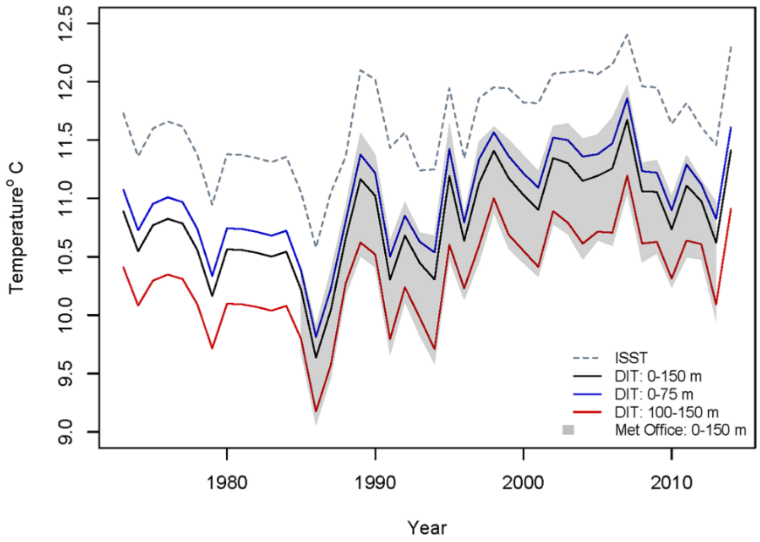

Figure 5.5. Depth integrated temperature of the Irish Sea from 1973–2014.

Finally, Figure 5.6 shows an early indication of ecosystem linkages in the Irish Sea. This plot highlights the apparent correlation between the biomass of adult cod in the Irish Sea and the Inverse NAO trend. The inverse NAO trend has been consistently estimated by the model as a primary production anomaly during the formal fitting procedure. Adding this trend to the model helps catch residuals and increase the models capacity to replicate stock trends.

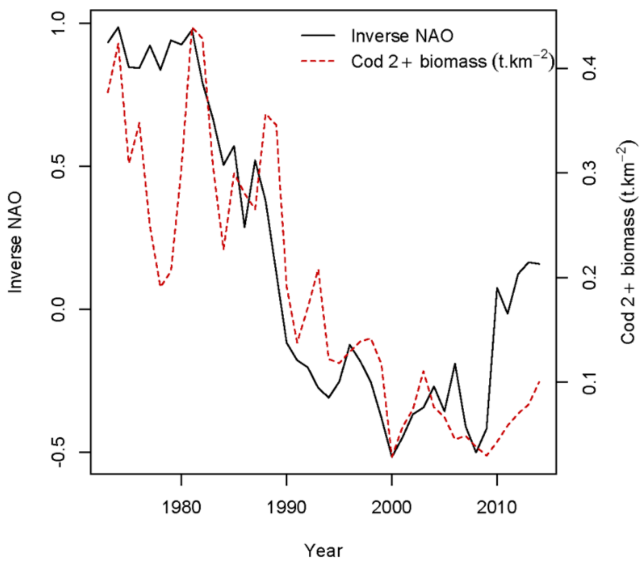

Figure 5.6. Correlation between the biomass of adult cod in the Irish Sea and the Inverse NAO trend.

6 Initial outputs from the LeMans framework modelling (addressing ToR c)

6.1 Model Framework

The fish community model is based upon the LeMans framework (Thorpe *et al*., 2015; 2016; 2017), with the fish community being represented as a two-dimensional field, being structured by length and species. The model represents around 40 fish species (Table 6.1) in up to 50 length classes (starting at 2 cm width, and increasing in width at larger sizes), spanning the full size-range of species represented in the model. The maximum rate of progression of individuals through length classes is represented using the deterministic von Bertalanffy growth equation (VBGE), with growth being subject to food limitation if there is not enough available food to support growth at this rate. Individuals mature when they reach a threshold size defined by a logistic model, with 50% of individuals mature at the length of maturity (L_{mat}). Reproduction is via a power-law relationship, which determines the numbers of recruits entering the smallest size class from the biomass of mature individuals. Species' dynamics are linked via predation mortality (M2), which varies with predator abundance, and size and species preference. Size preference is described with a preference function based on a lognormal distribution and species preference with a diet matrix indicating who eats whom (Rochet *et al*., 2011; Thorpe *et al*., 2015). In each length class, individuals are also susceptible to residual natural mortality (M1- a combination of environmental shock acting on small individuals, and senescence on larger/older ones) and fishing mortality (F). An ensemble approach is used, based upon a "filtered ensemble" (FE) of models drawn from a much larger population of 78 125 candidate models (the "unfiltered ensemble" or UE), with the FE being selected on the basis of the individual member's ability to persist stocks when unfished, and to simulate assessed abundances of stocks to an acceptable degree. As applied in the North Sea, this ensemble approach is described in detail in Thorpe *et al*. (2015). Further details on model structure and implementation are provided in Hall *et al*. (2006) and Rochet *et al*. (2011), with key parameters and equations summarized in Tables 6.2 and 6.33. The model time-step is currently $^{1}/_{18}$ of a year.

6.1.1 Model fitting

The model outputs will be fitted to survey data to match the measured abundances and length (example diagnostics for the North Sea are shown in Figure 6.1 and Figure 6.2). The survey data have been corrected for differential catchability using the method of Walker *et al*. (2017).

6.1.2 Model inputs

The model needs an estimate of the initial state of the system (this can be very approximate), and time-series of fishing mortalities on all the stocks. It also needs estimates of the numbers of seals and cetaceans in the form of time-series of numbers of individuals.

6.1.3 Outputs for single species assessments

Once tuned, the model outputs can be used to provide boundary conditions for single species assessments. Figure 6.3 shows an example showing projected predation mortality-at-age for plaice, showing what might be available. The model output often suggests quite different patterns from those typically applied to single species assessments, and has the potential to be useful as a sensitivity test for the latter.

6.1.4 Outputs for management advice

The model can be used to evaluate management strategies across the fish community. Figure 6.4 shows an example hindcast for the North Sea, illustrating how the management outcomes have changed (improved) with time.

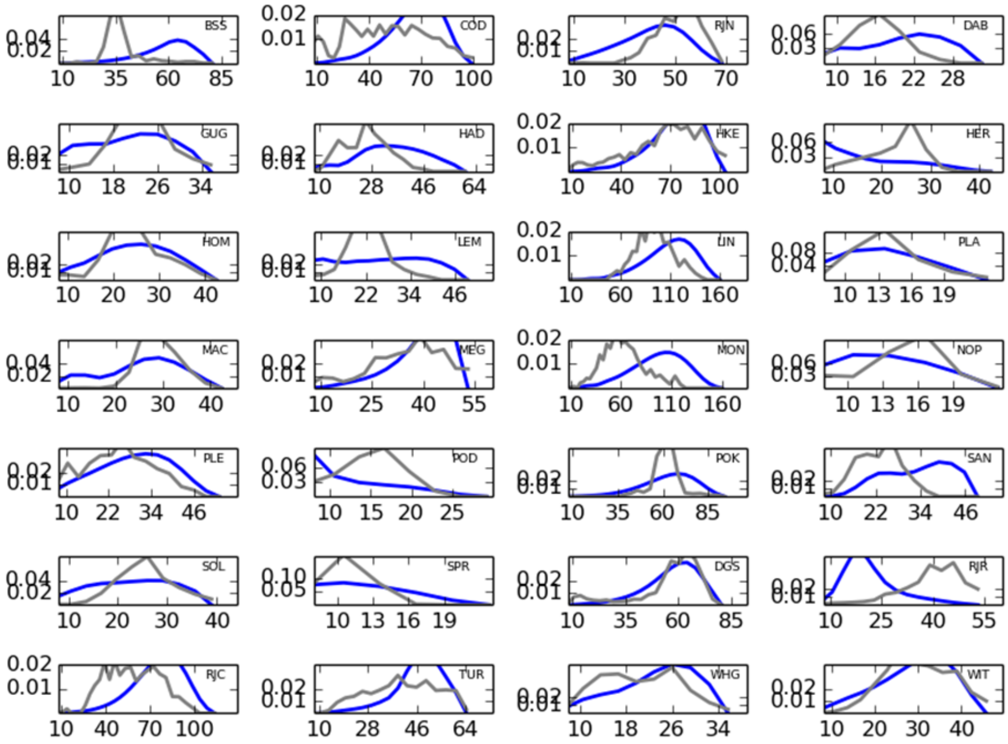

Figure 6.1. Example output showing correspondence between model biomass structure (blue), and estimates from catch-corrected survey data for the finfish stocks in the North Sea model.

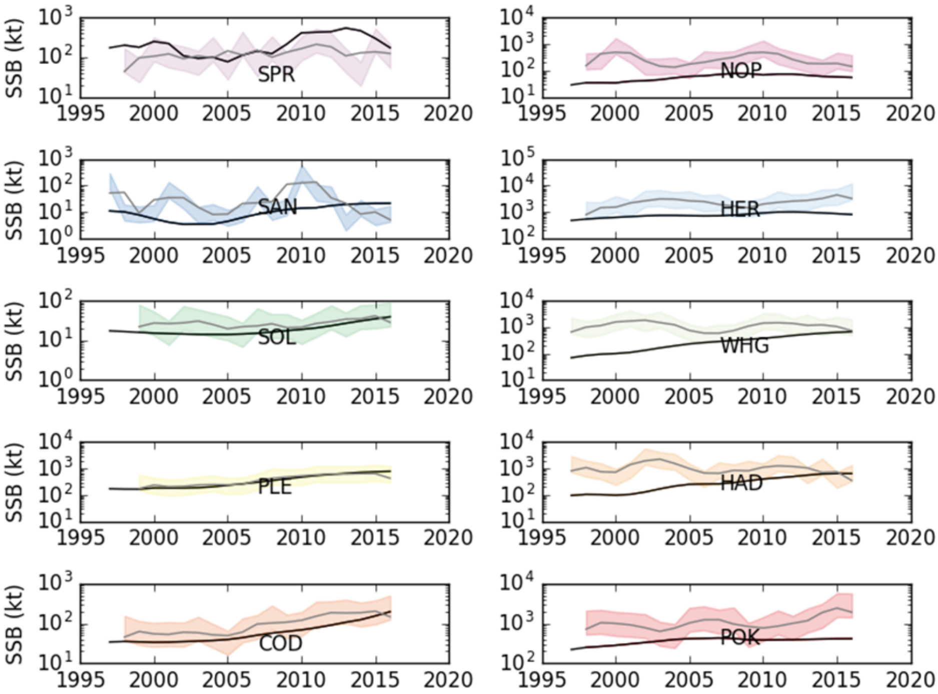

Figure 6.2. Comparison between catch-corrected survey data (grey line) and model estimate (black line) for the ten assessed North Sea stocks.

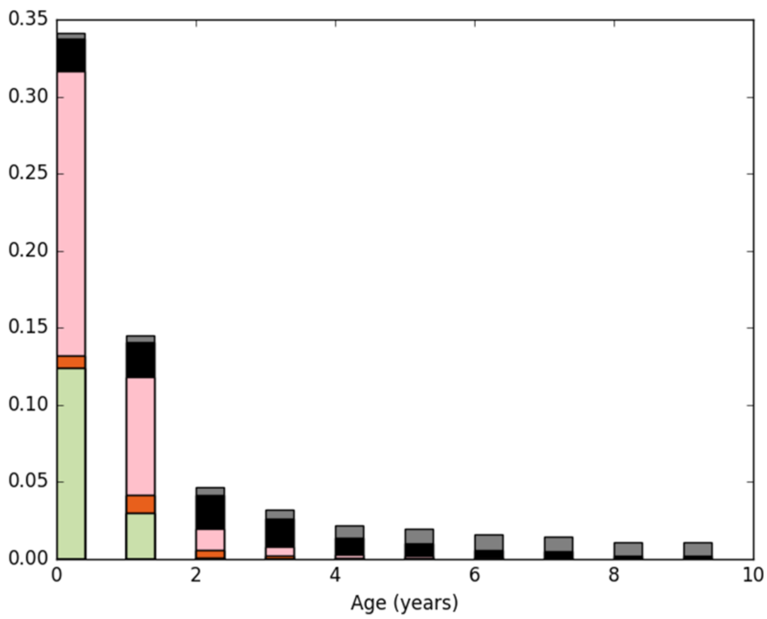

Figure 6.3. Predation on plaice as a function of age and source. Green = whiting, orange = cod, black = dolphins, grey = seals, pink = non-assessed stocks. In this example, predation declines steeply with age. On 0-group cod it is above the standard 0.2, but is lower for all other ages. Whiting is a key predator of small plaice, but the largest ones are eaten mostly by seals.

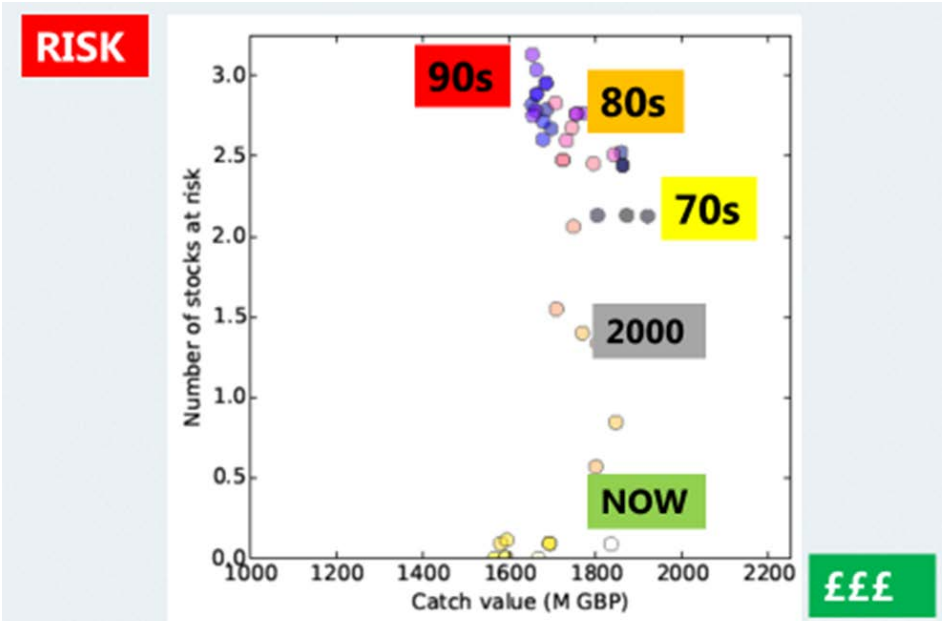

Figure 6.4. Management outcomes in the North Sea, for fishing strategies based upon constant fishing for each of the years 1970–2015. Good outcomes ((high yield, low risk) are in the bottom right, outcomes above 1 on the Y axis are not precautionary.

Table 6.1. Proposed list of stocks in the model.

Anchovy	Bib	Blonde ray	Bluefin tuna
Blue whiting	Cod	Common dragonet	Cuckoo ray
Dab	Gobies	Greater spotted dogfish	Grey gurnard
Haddock	Hake	Herring	Horse mackerel
Lemon sole	Lesser spotted dogfish	Lesser weaver	Long rough dab
Mackerel	Monkfish	Nephrops	Norway pout
Plaice	Pogge	Poor cod	Red gurnard
Red mullet	Sandeel	Scaldfish	Smooth hound
Sole	Solenette	Spotted dragonet	Spotted ray
Sprat	Spurdog	Thickback sole	Thornback ray
Tope shark	Tub gurnard	Whiting	Witch
Ling	megrim		

Table 6.2. State variables and parameters (adapted from Hall *et al.*, 2006).

Symbol	Description	Units/ notes
$N_{i,j}$	Number of individuals of species *i* in length-class *j*	Individuals
$W_{i,j}$	Weight of individuals of species *i* in length-class *j*	g
$B_{i,j}$	Biomass of all individuals of species *i* in length-class *j*	g
R_i	Number of recruits of species *i* in any given year	Individuals are added to smalles size class
t	Time	yr
T	Time to grow through one defined length class	yr
a_i	Length weight conversion for species *i* such that $W_{i,j} = a_i L_j^{b_i}$	kg cm^{-b}
b_i	Length weight conversion for species *i* such that $W_{i,j} = a_i L_j^{b_i}$	
L	Length	cm
L_j	Mean length of length-class *j*	cm
$L_{\infty,i}$	Von Bertalanffy asymptotic length of species *i*	cm
k_i	Von Bertalanffy growth parameter for species *i*	yr^{-1}
$\varphi_{i,j}$	Proportion of species *i* in length class *j* that moves to the next size class in a single timestep	
R	Recruits to smallest length class	numbers yr^{-1}
S	Spawning stock biomass	kt
$S_{\max, i}$	The maximum observed spawning stock biomass for species *i*	kt
$C_{\mathrm{mat}, i}$	Curvature parameter for the maturity ogive of species *i*	
$L_{\mathrm{mat}, i}$	The length at which 50% of species *i* are mature	cm
$\varpi_{i,j}$	The proportion of individuals of species *i* in length class *j* that are mature	
$F_{i,j}$	Instantaneous rate of fishing on species *i* in length class *i*	$timestep^{-1}$
η_i	Steepness parameter for fishing selectivity of species *i*	
$F_{\max, i}$	Maximum instantaneous rate of fishing for species *i*	$timestep^{-1}$
$L_{F50, i}$	The length of species *i* at which 50% fishing selectivity occurs	cm
$M_{i,j}$	Natural mortality of species *i* in length class *j*	timestep $^{-1}$
$M1_{i,j}$	Residual mortality (non-predation natural mortality) of species *i* in length class *j*	timestep $^{-1}$
$M2_{i,j}$	Predation mortality of species *i* in length class *j*	timestep $^{-1}$
$\xi_{n,j}$	Preference for prey species in length class *n* by predator in length class *j*	
$\tau_{m,i}$	Vulnerability of prey species *m* to predator *i*	0 or 1 from the d matrix
$\nu_{i,j,m,n}$	Suitability or relative preference of predator species *i* of length-class *j* for prey of species *m* of length-class *n*	
$I_{i,j}$	Ration that must be consumed by species *i* of length-class *j* of species i to grow in accordance with the von Bertalanffy relation	g
$G_{i,j}$	Growth efficiency: proportion of food consumed that is converted to body mass by species *i* of length-class *j*	

Table 6.3. Key mathematical equations and related quantities within model framework. Based on Hall *et al*. (2006) otherwise stated.

1	Growth	$L_{t,i} = L_{\infty,i}\,(1 - e^{-k_i(t - t0_i)})$	$t0_i$ length offset of species at t=0
2	Time to grow one length class	$T_{i,j} = \frac{1}{k_i}\log(\frac{L_{\infty,i} - L_{\mathrm{lower},j}}{L_{\infty,i} - L_{\mathrm{upper},j}})$	Where L_{lower} and L_{upper} are bounds of the length class
3	Proportion leaving length class	$\varphi_{i,j} = 1 / T_{i,j}$	Sets minimum timestep on assumption that no more than one class can be traversed per time step.
4	Recruitment	$R_i = \alpha_i S_i$ if $S_i < \beta S_{max,i}$ $R_i = \alpha_i S_{max,i}\beta$ if $S_i \geq \beta S_{max,i}$	Hockey stick spawner-recruit relationship. Initial slope α , break point $\beta \times S_{max}$ (Thorpe *et al*., 2015)
5	Fraction mature	$\varpi_{i,j} = \left(\frac{1}{1+e^{-k_i(L_{i,j} - L_{mat,i})}}\right)$	
6	Fishing mortality	$F_{i,j} = \frac{F_{max,i}}{1+e^{\eta_i(L_j - L_{F50,i})}}$	
7	Residual natural mortality $M1$	5 options considered in ensemble – see Table S1	Thorpe *et al*. (2015)
8	Growth efficiency, G	5 options considered in ensemble – see Table S1	Thorpe *et al*. (2015)
9	Ration, I	$I_{i,j} = \frac{a_i(L_{t,j}^{b_i} - L_{t-1,j}^{b_i})}{G_{i,j}}$	
10	Predation, $M2$	$M2_{m,n} = \sum_i \sum_j I_{i,j}\, N_{i,j} \frac{\nu_{i,j,m,n}}{\sum_i \sum_j \nu_{i,j,m,n} W_{m,n} N_{m,n} + \mathrm{oth}}$ • Expanded description below	Magnusson (1995)
11	Suitability	$\nu_{i,j,m,n} = \tau_{m,i}\,\xi_{n,j}$ Preferences are calculated via a log-normal distribution with parameter choices as in Table S1. Diet information comes from the ensemble member's diet matrix (see Table S1)	Thorpe *et al*. (2015)
12	Predation size preference, ξ	5 options considered in the ensemble (Table S1) Used with diet to calculate suitability.	Thorpe *et al*. (2015)
13	Diet, τ	5 options considered in ensemble (Table S1). Used with predation size preference to calculate suitability.	Thorpe *et al*. (2015)
14	Other food	1 x 10^{10}g, i.e. 60x less than Hall *et al*. (2006) and Rochet I. (2011).	Thorpe *et al*. (2015), set so as to approximate natural mortalities estimated by Sparholt (1990).

where W, N, and I are weight, abundance, and ration, respectively, for a given species; length class combination, "other food" is food available from prey that is not explicitly represented in the model, and $\nu_{i,j,m,n}$ is the relative preference (suitability) for predator i of size j for prey m of size n. This equation corresponds to a Holling type-II functional response, as implemented in MSVPA (Magnusson, 1995).

Although total feeding rate is constant in the model, predator feeding rate on a particular prey saturates at high prey abundance such that $M2$ is a decreasing function of prey abundance. The suitability parameter, ν, allows the total predator ration to be apportioned among prey species.

7 Stakeholder information on ecosystem impacts by gear for Integrated Ecosystem Assessment (addressing ToR d)

We took the opportunity at WKIrish to access stakeholder knowledge of the ecosystem impacts of fishing for the Irish Sea. The ODEMM (Options for Delivering Ecosystem-based Marine Management) method assesses impact chains (linkage pathways) between sectors, pressures and ecological components. A provisional Irish Sea assessment was produced in advance of the workshop using the Celtic Seas assessment (see WGEAWESS for details), by tailoring the ecological characteristics and relevant sectors for the Irish Sea. The Irish Sea assessment took both Irish and UK sectors into account for which the UK 'Charting Progress' reports were used to inform on the UK-relevant sectors and pressures. Provisional scores for each of the criteria assessed were assigned through a precautionary combining of the Irish and UK assessments. Due to the interests of this workshop, the sector 'Fishing' was further separated into; potting, dredging, beam trawling, bottom trawling, and pelagic fishing. This concept of an ODEMM assessment was presented to the WKIrish participants, and their contributions sought to review the assigned scores of the preliminary assessment. Despite being a complex and somewhat tedious task, the participants were willing to review the scores (five for each single impact chain), discussing the criteria and perspectives among the group before coming to a consensus. Individual knowledge and experience was able to inform the assessment on a finer scale than would be possible from a high-level expert group. Knowledge was forthcoming when it was available, and where it was not, participants advised us that it was outside their experience, very often recommending relevant people that may be able to help. Due to time constraints, the assessment was not completed during the workshop, however the stakeholders themselves decided they were willing to meet us again (on their own time) to finish the exercise at a later date. Overall, the exercise was informative and useful, and the willingness to engage demonstrated the perceived value of the exercise. Issues around terminology were highlighted, demonstrating the importance of clear communication and flexibility in interdisciplinary research.

Some of the results from this exercise can be seen in Figure 6.1 comparing before and after stakeholder input. Panel 1 shows the Impact Risk scores (a combination of the spatial and temporal overlap, and the degree of impact scores). Panel 2 ranks these scores to better illustrate the differences between them. Panel 3 illustrates the Recovery Lag scores (a combination of Resilience and Persistence scores). Participants reviewed the precautionary scores assigned initially. This resulted in a decrease in the range of Impact Risk scores for Beam trawling, although the median value remained much the same. For Bottom trawling the Impact Risk scores remained similar, however the Recovery Lag increased their range (more impacts with recovery lags >ten years). The profile from Dredging remained relatively unchanged. The range of Risk and Recovery Lag Scores associated with Potting decreased, although the median values remained similar. The Impact Risk range of Pelagic Fishing contracted substantially, however further consultation with fishers active in this fleet are required to better discern pressure pathways and impact scores for this fleet.

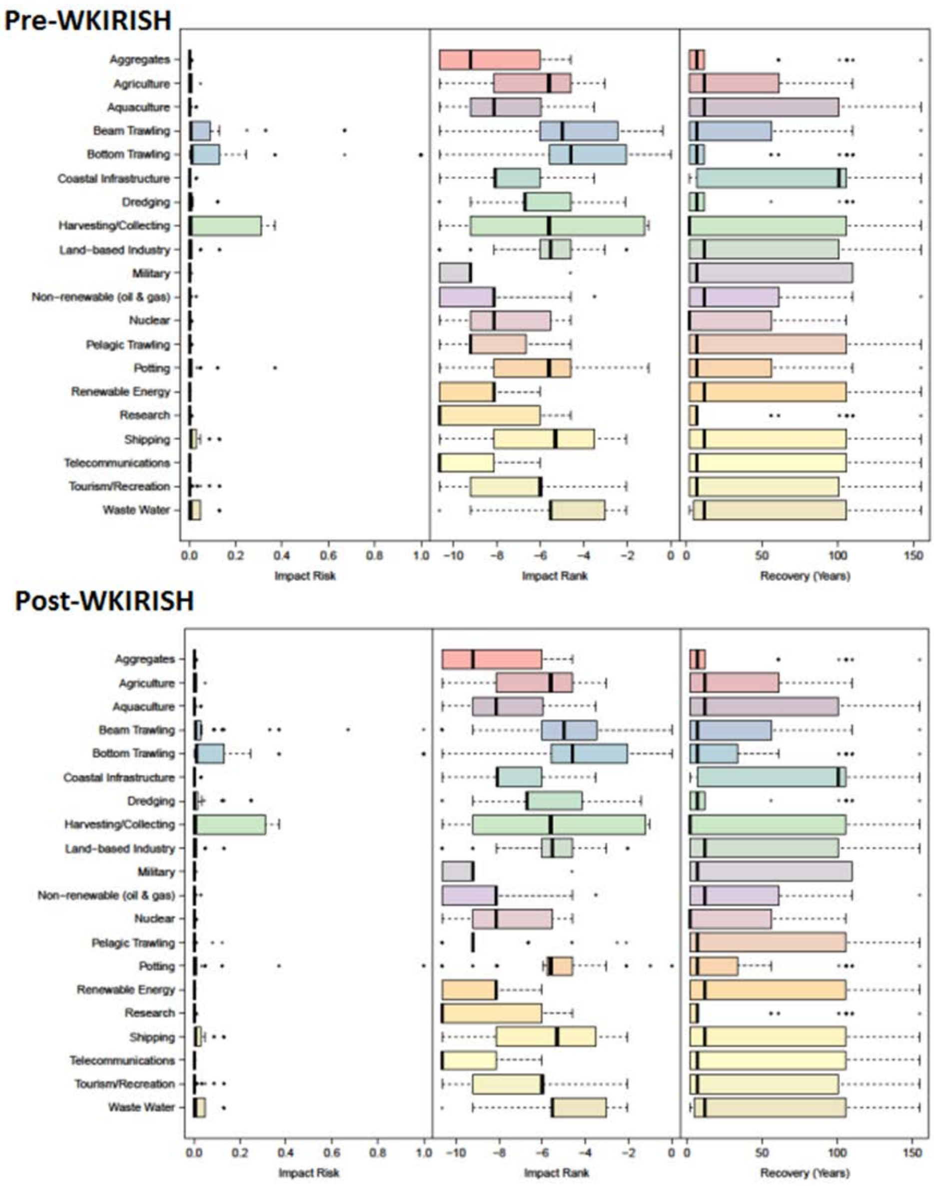

Figure 6.1. Comparison between sectors pre- and post-WKIRISH ODEMM stakeholder consultation.

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Annex 2: Agenda

Monday 6th November 10:00

10:00 Opening and Welcome, administrative details, and individual introductions

10:30 rest of day Presentations from participants on work relevant to the ToRs. This will be an open format session, where all participants will be able to present and discuss any relevant work as they request. Presentations should be 20–30 minutes. Presenters will also be asked to provide a short abstract of their material.

This will be continued until completed, we will plan for this to take up most of the first day.

Tuesday 7th November

Start 09:00

09:00–13:00 Open discussion on ToR a. This could be done as a strengths, weaknesses, opportunities and threats analysis, if participants agree.

14:00–17:30 Open discussion on ToR b. We should have information on a range of possible approaches (trawls, nets, acoustic, optical, etc.). This session should aim to provide information on each approach, and the state-of-the-art, plus what still needs to be done.

Wednesday 8th November

09:00–13:00 Open discussion on ToR c. What can or should be added to the existing survey design. This should include a cost benefit analysis, description of what any new data streams would be used for, and what would be needed to make these operational.

14:00–17:30 Open discussion on ToR d. This will probably largely follow on from the session on ToR c. It should focus on methods and techniques that may not be fully ready to be used, but which have potential for these surveys. Ideally, this should prioritise the methods chosen, and detail the work required to bring these to an operational level.

Thursday 9th November

All day

The session will focus on the upcoming H2020 calls for first:

- LC-BG-03-2018: Sustainable harvesting of marine biological resources. Specific Challenge: a large unexploited biomass in the mesopelagic zone!!

A consortium and proposal is underway for this call. Much of the methodology and techniques link very strongly with WKMESO ToR a and b. The aim would be to integrate the information on existing or potentially operational tools, and what would need to be done, as well as the research programme. The consortium would be led by Webjörn Melle (IMR), and hopefully we can start from the basis of a presentation from Webjörn

And second

- BG-07-2019–2020: The Future of Seas and Oceans Flagship Initiative, and specifically:
    - [B] 2018–2019: Assessing the status of Atlantic marine ecosystems.

This is a wider call than the BG3 one, but may potentially include many of the WKMESO participants. Mike St John (DTU-Aqua) is coordinating one response to this call, and is strongly linked to another (led by Xabier Irigoien, AZTI). Again, hopefully, we can start from the basis of a presentation from Mike, on the state of play for these proposals.

Friday 10th November

09:00–13:00 Assignment of any writing tasks, and planning for a way forward. This could include the need to have a follow-up workshop.

14:00 Close. The chairs anticipate that many delegates will plan to leave Bergen on Friday, so no formal activities are planned beyond this, but the time is available for text drafting and further discussion.