ICES WKIrish1 REPORT 2015

ICES Advisory Committee

ICES CM 2015/BSG:01

Ref. Acom, SciCom

Report of the Benchmark Workshop on sharing information on the Irish Sea ecosystem, stock assessments and fisheries issues, and scoping needs for assessment and management advice (WKIrish1)

14–15 September 2015

Dublin, Ireland

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2016. Report of the Benchmark Workshop on sharing information on the Irish Sea ecosystem, stock assessments and fisheries issues, and scoping needs for assessment and management advice (WKIrish1), 14–15 September 2015, Dublin, Ireland. ICES CM 2015/BSG:01. 37 pp. https://doi.org/10.17895/ices.pub.8711

For permission to reproduce material from this publication, please apply to the General Secretary.

The document is a report of an Expert Group under the auspices of the International Council for the Exploration of the Sea and does not necessarily represent the views of the Council.

© 2016 International Council for the Exploration of the Sea

Contents

Executive summary

The ICES Benchmark Workshop on the impact of ecosystem and environmental drivers on Irish Sea fisheries management (WKIrish1) was convened in Dublin, Ireland, 14–15 September 2015. There were 27 participants. These included representatives from the fisheries institutes with an interest in the region (MI, AFBI, Cefas and ILVO), as well as the Scottish Association for Marine Science and the Welsh Government. Stakeholder participation covered both the industry (NWWAC, NFFO(UK), Irish Fish Producers Organisation, and Irish South and East Fish Producers' Organisation), and the NGO participation from the Irish Seal Sanctuary, ClientEarth and the Marine Conservation Society. The meeting was chaired by David Reid (Ireland), Robert Thorpe (UK) and Scott Large (Denmark).

The aim of the workshop was to enable information exchange between management stakeholder groups, fishermen, scientists, regulators and other interested parties to improve understanding of the key issues involved and questions to be addressed.

Three main subject areas were discussed, covering ecosystem processes, fisheries issues, and management and policy issues. The group also identified data and tools that could assist the benchmarking process, and set priorities for future work. This can be summarized as follows:

Although open to both north and south, the bathymetry of the Irish Sea is relatively enclosed, and the area can be thought of as a large lake. The surrounding land includes large centres of population and is subject to intensive farming, whereas the marine environment is heavily used by both the industrial and tourist sectors. The fish stocks have overlapping spawning, nursery, and adult population zones, so the ecosystem as a whole is characterized by multiple overlapping usage and pressures.

The Irish Sea ecosystem has undergone considerable changes since 1960. A general increase in sea surface temperature is linked to increased northwards flow of warmer Atlantic waters, and a positive phase of the Atlantic Multidecadal Oscillation (AMO) and the increasing influence of global climate change. Cod, whiting, and sole spawning-stock biomass have decreased whereas herring and particularly haddock have shown signs of recovery in the more recent period. *Nephrops* landings have increased whereas those of other stocks have declined. At the same time, reductions in zooplankton important for fish recruitment have also been observed while concurrent increases in phytoplankton have been linked to possible reductions in grazing pressure. Meanwhile increases in ocean colour and gelatinous zooplankton may be linked to anthropogenic disturbance and climate.

Irish Sea fisheries have changed from a cod, whiting, sole and herring dominated fishery in the 1960s to one which is dominated by *Nephrops* and other shellfish stocks today. Since the early 2000s, ICES has been advising zero catch for cod and whiting. Despite effort reductions of >90% in the large-mesh otter trawl fleet, and other measures to recover the cod stock, there is little evidence of any stock response, suggesting ecosystem changes may be playing a role by modifying levels of natural mortality and thus offsetting the decline in fishing.

There is evidence of truncated age structures in most Irish Sea stocks. Key issues to be resolved include whether this pre-dates the onset of heavy exploitation, and whether it is caused by environmental conditions inside the Irish Sea or reflects net migration of mature fish. Metrics for maturity-at-length, and weight-at-age are decreasing, sug-

gesting that fish stocks are under pressure to mature more quickly, either as a result of high fishing pressure, natural mortality, or other environmental factors.

Management policy issues concern interactions between the three main fisheries, *Nephrops*, gadoids, and scallops/whelks. *Nephrops* and scallops are the most important economically, but the key mixed fishery interaction is between the *Nephrops* and several fisheries (e.g. gadoid and sole). One important issue in fleet management is to maintain the catches of marketable *Nephrops* while minimizing the catch of undersized specimens, and of cod, whiting, sole and haddock. Increasing the codend mesh size from 70 mm to 80 cm has proved the best option in trials, reducing discards of whitefish by 45% with only 5% loss of *Nephrops* yield. The impact of policy changes must be considered in the light of their economic impacts. Dublin and Louth are the ports most dependent on Irish Sea fisheries, and therefore the most likely to need economic assistance if management policy decisions reduce the yield of these fisheries.

In accordance with the Terms of Reference several sources of data and modelling tools were identified to assist with the construction of an ecosystem benchmark. Broad-scale characterization of the ecosystem state, drivers, and function in response to changes in climate, nutrient run-off, and fisheries can be provided by integrated ecosystem assessments, while the ecosystem management issues can be addressed using a framework such as Options for Delivering Ecosystem-based Marine Management (ODEMM), an approach which relates sectors, pressures, and ecological functions to provide management information on the basis of expert review. EcoPath was identified as a suitable tool for looking at the impact of changes in ecosystem energy flows on the fisheries, potential resources such as zooplankton, and potential problem issues such as increasing numbers of jellyfish. The LeMans ensemble modelling approach can be used to look at the impacts on the fish community and managing the risk of stock depletion and long-term loss of yield. AFBI detailed a wide range of survey activity covering different seasons, areas, and stocks, which can be used to provide ground-truthing for the models, while ILVO can offer genetic testing of the sole stock to ascertain any changes in migration patterns to inform the modelling effort.

The group felt that priorities for action included a) improving the quality of the existing analytical single-stock assessments, b) documenting the special features of the Irish Sea that need to be reproduced by models, including the lack of response to massive effort reduction in the TR1 otter trawl fleet, strongly truncated age structure, spawning areas, and impact of gyre circulation changes on fish stocks, c) ascertaining how long the truncated age structure has persisted, d) improving our understanding of the level of migration of mature fish north and south out of the Irish Sea, perhaps using the ^{14}C signature of Sellafield as a suitable "tag", e) developing a multispecies model framework that can reconcile/integrate the (improved) analytical stock assessments, and f) honestly representing uncertainties using a combination of ensemble and multi-model investigation.

1 Introduction and expectations

1.1 Background and Rationale for WKIrish1

The ICES 2014-2018 Strategic Plan calls for developing integrated ecosystem assessment methodologies and approaches that can be used to address both specific advisory questions and broader ecosystem issues. As the first ICES Integrated Benchmark, the Irish Sea Integrated Benchmark (WKIrish) has several challenges that will benefit from a more holistic approach beyond the development of single-species assessment methods. Irish Sea fisheries have transitioned from a cod, whiting and herring dominated fishery in the 1960s to one that is dominated by *Nephrops* and other shellfish stocks today. Overall fishing effort has reduced by around 40% and large mesh otter trawl effort has reduced by 80%. Reductions in effort and other measures to recover the cod stock have resulted in little evidence of any stock response, suggesting a more holistic exploration of ecosystem and ecological aspects (e.g. various sources of natural mortality) is necessary.

WKIrish process is a 2-year project that includes a series of workshops and intercessional work that focuses on improving single-species stock assessments (principally cod, haddock, whiting, plaice, and herring), incorporating a mixed fisheries model, and developing the integration of ecosystem aspects and working towards an integrated assessment and advice. The four main workshops aim to address:

WKIrish1 (September 2015): Information sharing and scoping (Terms of Reference can be found in Annex 1);

WKIrish2 (January 2016): Data evaluation;

WKIrish3 (March 2016): Single-species stock assessment development;

WKIrish4 (October 2016): Development of an integrated ecosystem assessment and advice.

1.2 Expectations of WKIrish1

The ultimate objective is to improve ecosystem understanding so that we are able to provide better advice for Irish Seas stocks and fisheries; this requires integration of ecosystem knowledge and other useful knowledge stakeholders may possess, as well as identifying other aspects that could improve our fisheries advice. Therefore, input from stakeholders is vital for the development of ecosystem management plans for Irish Sea fisheries, which should involve the fishing industry, regulators, policy advisors and scientists. A broad spectrum of perspectives is needed so that:

- We understand the key issues involved and questions to be addressed.
- We develop the right tools to address them.
- The resulting ecosystem management has credibility and legitimacy.

Stakeholders can assist the process by providing an intimate knowledge of Irish Sea fish biology, ecology, and the social and economic implications of management actions. These in turn can inform ecosystem and stock assessment model development. Further, input from stakeholders can help weigh trade-offs between different management objectives, so what sort of impact can we allow on seabirds say, when we introduce the landing obligation.

2 Ecosystem considerations

Aspects of the Irish Sea ecosystem may be causing observed changes in the natural mortality of key stocks. Exploratory analyses considered the physical, chemical, and biological environment and the productivity of the main fish stocks associated with the Irish Sea. These analyses highlighted that the Irish Sea ecosystem has undergone considerable changes over the past several decades. Tools, such as ODEMM (Options for Delivering Ecosystem-based Marine Management) and boosted-regression analysis could be adapted to the Irish Sea to use a risk assessment framework and spatial management to assess and identify trade-offs between sectors and ecological characteristics. Further, mass-balance ecosystem (EcoPath with EcoSim) and length-based ensemble models (LeMans) can also be used to explore and simulate management options between single- and multispecies management and the ecosystem. Brief descriptions of each presentations on ecosystem considerations can be found, below.

2.1 Preliminary Integrated Ecosystem Assessment of Irish Sea

The results of a preliminary Integrated Ecosystem Assessment (IEA) of the Irish Sea were presented to the group. IEAs consider the physical, chemical, and biological environment – including all trophic levels and biological diversity – and treat fish and fisheries as an integral part of the ecosystem (Diekmann and Möllmann, 2010). The approach has been shown to be useful in defining ecosystem state and in understanding function and drivers in a holistic manner. IEAs take into consideration a suite of indictors representing the biotic components and abiotic drivers of the ecosystem. For the Irish Sea, time-series (1971-2013) of abiotic and biotic indictors describing the climate, hydrography, nutrients, phytoplankton and zooplankton, fish and fisheries were assembled from various sources and analysed according to Diekmann *et al*. (2012).

Pronounced changes in the Atlantic Multidecadal Oscillation (AMO) and the winter North Atlantic Oscillation (NAOw) suggest changes in atmospheric forcing in the Irish Sea. Hydrographic conditions in the Irish Sea are largely influenced by these environmental drivers. Interannual variability of sea surface temperatures (SST) is illustrated by the AMO, which is currently in a warm phase. The NAO is more variable with positive phases associated with stronger westerly winds and increased precipitation. Nutrient data taken from Cypris site highlight changes in nitrogen (N) and phosphate (P) levels, reflecting riverine inputs via anthropogenic sources (Gowen *et al*. 2002). Increased precipitation and river flow will likely result in increased nutrients in coastal areas. Winter (January and February) concentrations of P have declined since the late 1980’s thought to be in part due to the reduction in P usage in detergents (Gowen *et al*., 2002).

The Phytoplankton Colour Index (PCI) is a measure of the diotom and dinoflagellate biomass (Richardson *et al*., 2006), which increased over the time-series. Dinoflagellates and diatom counts, representing larger phytoplankton cells had a more varied pattern over time. Trends in zooplankton assemblages deemed important to fisheries (i.e. copepods, *Calanus* sp., Euphausiids, and gelatinous material) were analysed, all copepods showed lower relative abundance in the latter part of the time-series with the possible exception of *Calanus* sp. stages V–VI, which includes stages V–VI of *Calanus finmarchicus* and *Calanus helgolandicus*. Gelatinous material and decapod larvae both increased in the recent period.

Single-stock assessment outputs data for cod, sole and herring and landings data for *Nephrops*, were used to represent changes in the demersal, pelagic and *Nephrops* fisheries. The trends highlighted the declines in sole and cod spawning–stock biomass (SSB) and recruitment.

Overall the analysis highlighted that the Irish Sea ecosystem has undergone considerable changes over the period. An increasing trend in SST over the time-series linked to the positive phase of the AMO and increasing influence of global climate change. During this period declines in cod and sole SSB have occurred while herring have shown signs of recovery in the more recent period. *Nephrops* landings have increased over the period related to declining opportunities in other traditional species. Declines in zooplankton important for fish recruitment have also been observed while concurrent increases in phytoplankton have been linked to possible reductions in grazing pressure (Lynam *et al.*, 2011). Meanwhile increases in gelatinous zooplankton may be linked to anthropogenic disturbance and climate.

2.2 Irish Sea Gadoid Productivity

The Irish Sea contains a number of historically commercially important gadoid stocks, cod, haddock and whiting, as well as important spawning and nursery areas for all three species. As with elsewhere in the North Atlantic, many of these have been subject to high levels of fishing mortality leading to reduced SSB and truncated age structures. As such, Irish Sea cod and whiting are currently assessed as below biomass management reference points, i.e. at very low biomass. Concurrent with reductions in SSB, whiting have exhibited reduced recruitment in the face of high discarding mortality and reductions in weight-at-age, while a negative correlation between cod recruitment and SST highlights environmental drivers of Irish Sea cod productivity. In contrast haddock has seen intermittent increases in stock size driven by strong recruitment events.

Differences in the productivity and population growth of these gadoid species have occurred despite similarities in spawning seasonality, with all three species beginning spawning during early spring, leading to considerable overlap in early life-history distributions. The productivity of a fish population is largely determined by a combination of the reproductive output of the parent stock and highly variable mortality occurring during the early life-history stages (egg, larval and early juvenile stages). The ability to relate changes in productivity to population, environmental and ecosystem variability is therefore central to successful ecosystem based fishery management. Using a time-series encompassing multiple life-history stages of cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) in the Irish Sea, the dynamics of productivity were explored. Paulik analyses were presented illustrating annual variability of the relative abundance of early life-history stages. Results of the work show that the annual variability of productivity of cod and haddock is largely determined during the early life-history stages (eggs, larvae, pelagic juveniles), while processes during the juvenile demersal stage may also be important. Trends between the three species in abundance and mean length of early pelagic juveniles suggest that common selective mortality processes operating via physical and/or biological processes may play a key role in the productivity dynamics of these stocks in the western Irish Sea. A negative correlation between SST and recruit abundance is suggestive of an environmental link with these processes.

Preliminary work was presented showing the link between the timing of stratification in the western Irish Sea and local climatic conditions (windspeed and SST). These climatic conditions were in turn linked to the relative success of haddock vs. cod recruitment in the region. Local climatic conditions could influence early life-history survival through dispersal and feeding mechanisms, while species-specific spawning strategies could lead to varying productivity patterns observed between the three stocks.

2.3 Spatial management of data-poor elasmobranchs using Boosted Regression Tree modelling

Skates and rays represent one of the most vulnerable components of the fish community in temperate demersal fisheries such as the Irish Sea. They also tend to be data-poor compared with commercially exploited teleost fish. Spatial management has been suggested as an important tool in protecting these species, but this requires an understanding of the abundance distribution, and its relationship with the environment at both adult and juvenile life-history stages. In this analysis, delta lognormal boosted regression tree models were used with bottom-trawl survey data to derive rays' spatial abundance, and environmental links. The modelling approach allowed the development of detailed predictive maps of abundance of four common and rare skate and ray species implicated in the fishery: thornback, spotted, cuckoo and blonde rays. The distributions were driven by a general preference for sand and courser substrata, higher salinities, temperatures and currents speeds. The abundance distribution maps were examined together with maps of skate and ray commercial landings, suggesting that the main hot spots for the species were away from the main commercial fishing areas. The maps were also compared to potential MPAs proposed for wider ecosystem protection, and the main hot spots were well covered by the proposed MPAs. This combination of the main abundance hot spots in areas of low fishing, and wider potential ecosystem protection, suggests good potential for spatial management measures to protect these species in the Irish Sea. The methodology has been extended to encompass commercial fishing and predation by larger fish, as well as to automatically suggest optimal MPAs based on minimizing fishery impact while still maintaining precautionary point biomass, B_{pa}. This complex methodology is bundled into an R package that enables environmental scientists and fisheries managers to enjoy the benefits of these powerful statistical approaches without having to become an R expert.

2.4 Irish Sea ODEMM Pressure Assessment

To deliver holistic ecosystems-based marine management, managers must know the factors affecting the ecosystem if they are to manage/mitigate for them. Here, a risk assessment framework, based on the EU FP7 funded ODEMM (Options for Delivering Ecosystem-based Marine Management) approach, was presented. The framework traces the multiple sectors affecting the marine environment, the pressures they create, and the ecological characteristics affected by them. Scores are assigned by an expert panel detailing the extent, overlap, degree of impact, persistence and resilience for each pressure pathway, based on predetermined thresholds. From this information, pressure matrices are created that can be used to calculate scores to indicate an overall impact risk score and recovery timeline estimates. Further, this information can be used to create easily interpretable and understandable tools for communicating complex messages in a simple format to non-scientists such as policy-makers and stakeholders. These methods allow the creation of simple bar charts that indicate the 'proportional connectance', allowing viewers to easily rank sectors, pressures or ecological characteristics according to how many connections exist (e.g. the highest ranking sector, creates the most pressures, affecting the most ecological characteristics). Next, linkage dendrograms can be built, intuitively illustrating relationships between sectors, pressures or ecological characteristics through grouping of the most similar components. This step is important for communication as it highlights that when similar sectors cluster together, there is little point in tackling the pressures associated with only one of the sectors, as the sectors that cluster near each other cause a similar array of pressures and so they must be targeted together. Finally, boxplots can be produced to illustrate the risk factor, and the expected recovery timelines for each sector, pressure and ecological characteristic, helping to enlighten stakeholders and enabling policy-makers to make informed decisions. In light of the complex landscape of ecosystem-based management and the Marine Strategy Framework Directive, these tools have a real benefit in the simplicity of their interpretation and understanding.

This framework has thus far been implemented with success for the Celtic Seas. It was presented at WKIrish as a possible tool for use within the Irish Sea. It has been suggested to adapt the framework from the original analysis to categories that are particularly relevant to the Irish Sea and the WKIrish: for instance, the splitting of the sector 'Fishing' into specific gear related groupings. In order for this to be successful, an Irish Sea specific expert panel review would need to be carried out to assign scores for each pressure pathway.

2.5 Using ecosystem models for sustainable management of the Irish Sea

Ecosystem models are important for converting the data collected in the field to information, to be used as evidence of policy implementation (Hyder *et al*., 2015). The UK has significant ecosystem modelling capability (Hyder *et al*., 2015), and we have quite a significant ability in EcoPath with EcoSim (Christensen and Walters, 2004; Heymans *et al*., 2014) specifically in the Irish Sea and on the West Coast of Scotland (Figure 1; Lees and Mackinson, 2007; Alexander *et al*., 2015). The Irish Sea EwE model is currently being updated in the Lo-Rise project (https://www.bgs.ac.uk/rate/LO-Rise.html) in combination with the model of the West Coast of Scotland (Alexander *et al*., 2015). Lo-Rise is a project where we are tracing radioactive ^{14}C through the foodweb based on the output from Sellafield. For this project we will model the northern Irish and Southern Scottish waters (blue below). In MERP (http://www.marine-ecosystems.org.uk/) we are updating the West Coast model (Alexander *et al*., 2015) to examine the ecosystem services provided by kelp, but also looking at the ecosystem services provided by this ecosystem as a whole.

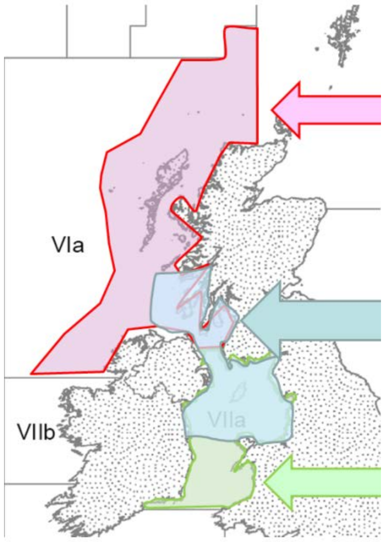

Figure 1. Spatial extent of EwE models: Red, West Coast of Scotland; Green, Irish Sea; Blue, northern Irish and Southern Scottish waters.

2.6 Multispecies fish community modelling

Robert Thorpe gave a presentation on multispecies fish community modelling, covering the legislative background, scientific justification, the concept of a multispecies "maximum sustainable yield", and examples from the North Sea of the relevant methodology and some initial findings.

The key messages of the presentation were:

a) Managing the fish community requires that the tension between maximizing short-term returns and preserving the long-term health of the system be addressed, so it involves a trade-off between risk and yield.

b) Legislation states that this trade-off must reflect issues connected with mixed fisheries (where different stocks are caught together) in a multispecies framework (taking ecological interactions between different stocks into account).

c) MSY (maximum sustainable yield) addresses this risk/trade-off, and is intuitive for a single stock, but hard to define for a fish community.

d) We look at the fish community response using an ensemble-based modelling system (Thorpe *et al*., 2015) to generate probabilities of stock impairment (risk) alongside traditional measures of yield.

e) Using this framework in the North Sea, we have shown that the management regime there is reducing risk without sacrificing yield, and is likely over time to facilitate stock rebuilding.

f) We propose to build a similar model framework for the Irish Sea to produce multispecies/mixed fisheries advice.

g) Multispecies interactions can result in an ecosystem shifting irreversibly to a different state, as a result of feedbacks which are not normally considered in traditional stock assessment. We will use our model to investigate whether a regime shift of this nature is happening or has happened in the Irish Sea.

3 Fisheries considerations

There has been a major shift in Irish Sea fisheries over the last 40 years, away from the traditional gadoid species (cod, whiting and to a lesser extent haddock) and towards *Nephrops*, which is now much the most important fishery. This reflects the effective collapse of the cod and whiting stocks during this period, and the increasing abundance of *Nephrops* in the Irish Sea. The failure of cod and whiting to recover despite a massive reduction in the TR1 otter trawl effort is in contrast to the picture in the North Sea and for other ecoregions (where effort management has been successful in restoring stocks) and is currently unexplained.

3.1 Data Resources from Agri-Food and Bioscience Institute

A presentation was given providing an overview of the existing data resource collected and managed by the Agri-Food and Bioscience Institute (AFBI). The presentation provided a summary of the relevant fisheries-independent and fishery-dependent data resources. The potential use of these survey time-series to establish community scale patterns across multiple species was described. A further, common trend in biological parameters, maturity and growth, of different species was explored using data from the sampling programme undertaken during research surveys. The fishery-dependent sampling programmes, managed by AFBI, were described and their use to explore fishery spatial and temporal patterns presented.

Within the presentation an overview of the fisheries-independent survey series collected by AFBI was presented, this included; a description of spring and winter demersal fish surveys, summer camera and trawl survey for *Nephrops*, the autumn acoustic survey targeting pelagic species and surveys for juvenile stages of gadoid species and herring. The data collected during surveys were detailed to inform the audience of the availability of the survey time-series, species abundance metrics, length frequencies and biological parameters.

The fisheries-dependent data collection programmes in the Irish Sea, managed by AFBI, were presented. The sampling schemes describe included; port sampling of commercial landings, a fisher self-sampling programme and observer sampling at sea. The use of these data sources to describe commercial fishery patterns was presented along with description of opportunities to map aspects of commercial catches within the Irish Sea.

Feedback and discussion generated from the participants concerned:

- The ability to integrate the data managed by AFBI and other sources, such as those managed by the Marine Institute;
- Discussion of the differences in the patterns of commercial fishery catches and species distributions observed in surveys;
- Further spatial and temporal analysis of biological changes and update of previous findings now with longer time-series.

3.2 Whiting in the Irish Sea

For over 40 years, 1950–1990, there was a targeted human consumption fishery for whiting in the Irish Sea yielding on average 10 000 t of landings/annum. After 1990 there was a rapid decline in landings to the <200 t we see today. The discard volumes in the *Nephrops* fishery have remained at a similar level throughout the time-series at ~2000 t/annum (Figure 3.1.1).

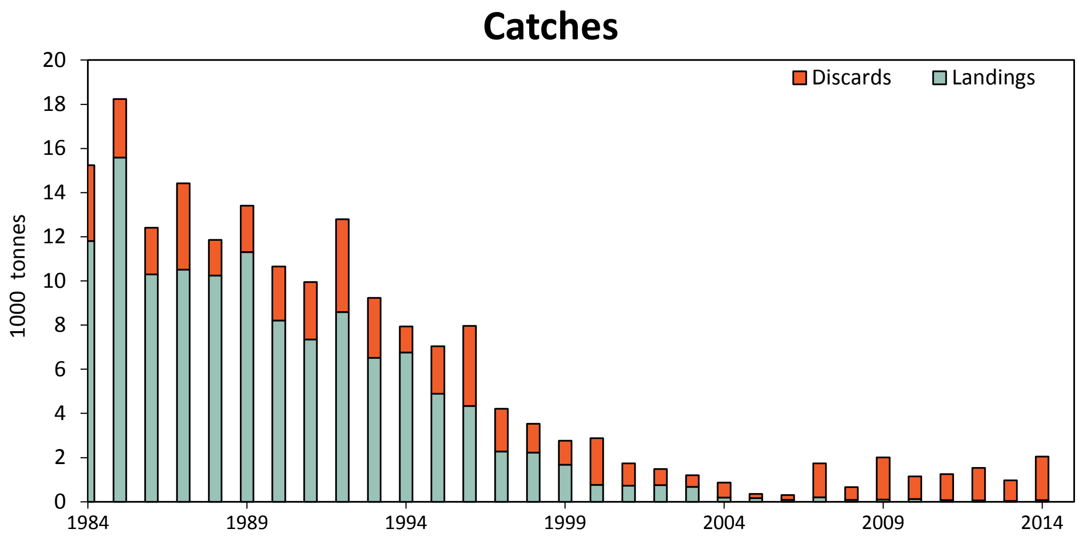

Figure 3.1.1. Time-series of landings and discards in whiting VIIa

The last full age-based analytical assessment for whiting in the Irish Sea was carried out in 2003. Since then SURBA trends from two Northern Ireland groundfish surveys, March and October, have been used to monitor stock development (Table 3.2.1). Both surveys show large reduction in SSB around 2004 though the reason for this is unknown. Despite a large reduction in fishing effort in the TR1 fleet and numerous technical conservation measures in the TR2 fleet there is no evidence from any of the scientific data for an improvement in stock status. In addition there has been a significant reduction in mean weight-at-age since the 1980s (Figure 3.2.2). Although previous studies showed no evidence of a shift in maturity (Gerritsen *et al.*, 2003) more recent data presented at WKIrish1 appeared to show that there may have been reductions in maturity-at-age also. A migration of recruits out of the Irish Sea is one of the postulates put forward to explain the lack of stock recovery but there are no scientific data to support this hypothesis.

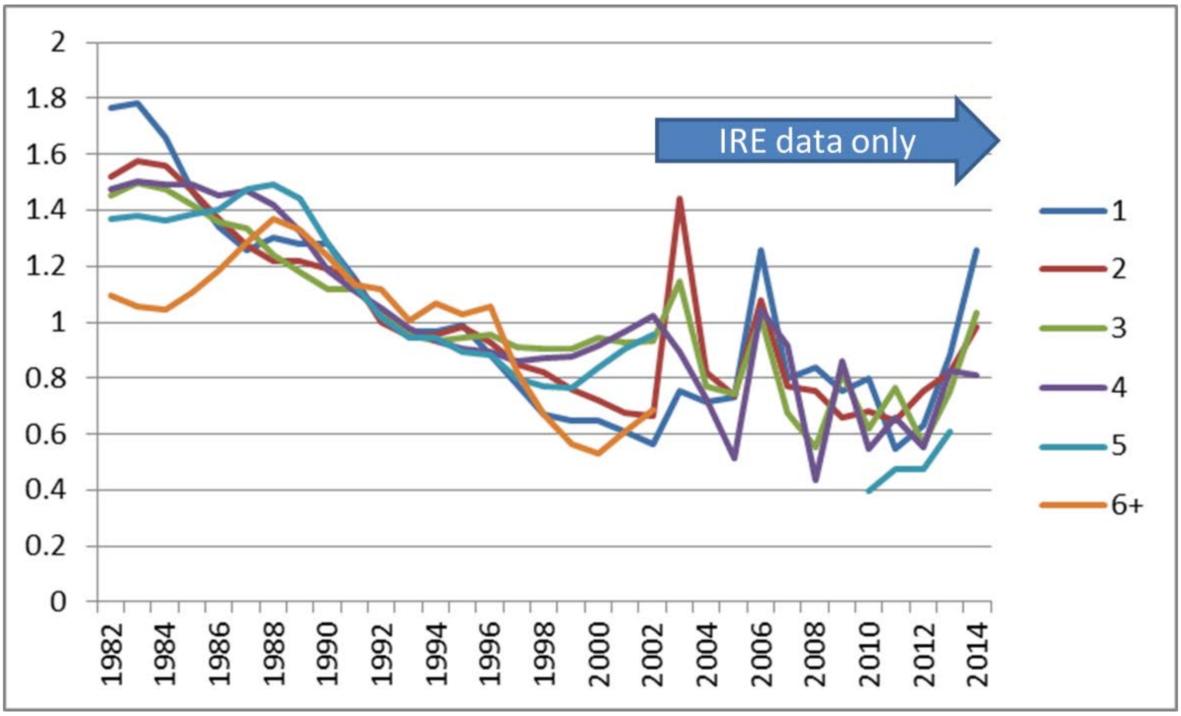

Figure 3.2.2. Mean standardized weights-at-age for whiting in VIIa.

The ICES advice has been for zero catch since 2001. As the landing obligation is implemented whiting has the potential to become a major choke species in the Irish Sea *Nephrops* fishery. Clearly there are significant biological and productivity changes to this stock. Whether these changes have been brought about by the fishery or by other ecosystem factors is a key scientific question to be explored by WKIrish. The process will attempt to document biological changes observed in survey and fishery data. The aim is to try to like these to other ecosystem changes. In parallel the impact of changes in the stock assessment through changes in M, weights and maturity and to fishery data through changes in selectivity and/or catchability will be explored. From a management perspective the main questions are: What is the capacity of the stock to recover? What are the potential costs associated with a recovery?

Table 3.2.1. Summary of history of the stock assessments for Irish Sea Whiting.

Year	Reference	Assess. method	Commercial cpue used	Surveys used	Comment
1991	C.M. 1992/Assess 2	Laurec-Shepherd	NI; E&W trawl	none	Separate assessments presented for E&W and NI commercial cpue tuning data due to conflicting trends. ACFM re-combined the assessment.
1992	C.M. 1993/Assess 2	Laurec Shepherd	NI seasonal otter/pel combined; E&W otter	none	Conflicting trends from commercial cpue still observed; combined assessment presented.
1993	C.M. 1993/Assess 20	XSA	As 1992	Irish GFS; E&W BTS, GNS and N.Wales GFS	Survey data included, but mostly weighted out. NI commercial cpue gave lower survivors and higher F than E&W otter trawlers.
1994	C.M. 1995/Assess 1	XSA	As 1992	As 1993	Misreporting from 1991 onwards included in this and subsequent years. Different commercial cpue trends noted.
1995	C.M. 1996/Assess 1	XSA	As 1992	Irish GFS; NI GFS (March, Oct); E&W BTS	No problems with assessment noted by WG
1996	C.M. 1997/Assess 2	XSA	As 1992	NI GFS (March, Oct); E&W BTS	Conflict between commercial cpue less apparent.
1997	C.M. 1998/Assess 1	XSA	As 1992	NI GFS (March, Oct)	New stock wts based on smoothed Q1 catch wts; consistent survivors estimates from all tuning fleets used.
1998	CM 1999/ACFM 01	XSA	As 1992	NI GFS (March, Oct)	Consistent survivors estimates from all tuning fleets used.
1999	CM 2000/ACFM 01	XSA	NI otter (incl discards); E&W otter	NI GFS (March, Oct)	Consistent survivors estimates from all tuning fleets used.
2000	CM 2001/ACFM 01	XSA	As 1999	NI GFS (March, Oct)	NI surveys and the UK(E&W) trawl fleet gave larger survivors and lower F than NI otter fleet.

Year	Reference	Assess. method	Commercial cpue used	Surveys used	Comment
2001	CM 2002/ACFM 02	XSA	As 1999 plus Irish otter trawl	NI GFS (March, Oct)	NI surveys and the UK(E&W) trawl fleet gave larger survivors and lower F than Irish and NI otter fleet. WG made extensive comment on conflicting trends in tuning data, and recommended an area-disaggregated assessement.
2002	CM 2003/ACFM 04	XSA; Surba	none	NI GFS (March, Oct)	Commercial cpue excluded. Substantial retrospective pattern of underestimation of F and overestimation of SSB in the terminal year, with unrealistically large catch forecasts. No ACFM forecast.
2003	CM 2004/ACFM 04	XSA; Surba	none	NI GFS (March, Oct): western Irish Sea only	Heavily shrunk XSA carried out to give forecasts for mixed fishery model, using western Irish Sea survey data to tune XSA.
2004	CM 2005/ACFM 04	SURBA	none	NI GFS (March, Oct)	Absence of sampling data for landings and discards in 2003, plus large year-effects in recent surveys, result in no assessment presented.
2005	CM 2005/ACFM 13	SURBA	none	NI GFS (March, Oct)	Various catchability settings were used in the single fleet SURBA no major effect on the results. No commercial data available since 2003.
2006	CM 2005/ACFM 30	SURBA	none	NI GFS (March, Oct)	Surba update
2007	CM 2005/ACOMXX	SURBA	none	NI GFS (March, Oct)	Three different configurations of the NIGFS surveys. The conclusion was that there is no strong evidence at present to justify keeping these indices separate.
2011	CM 2005/ACOMXX	SURBA	none	NI GFS (March, Oct)	Surba update
2013	CM 2005/ACOMXX	SURBA	none	NI GFS (March, Oct)	Surba update
2015	CM 2005/ACOMXX	SURBA	none	NI GFS (March, Oct)	The NIGFS-WIBTS-Q1 survey shows a decline in SSB in the terminal year whereas the NIGFS-WIBTS-Q4 survey shows an increase in the terminal year. Overall SSB is still at low levels compared to earlier on in the time-series.

3.3 *Nephrops* in the Irish Sea

The main fishery in the Irish Sea is the *Nephrops* fishery. The largest patch is in the western Irish Sea FU15. This fishery has been fairly stable since the 1960s with around 9000 t of landings and 10 500 t of catch annually. The data here are relatively good with large numbers of samples taken annually and a dedicated UWTV survey and trawl survey. The scientific advice is based on the UWTV survey. There is also a large body of literature on the recruitment process for this stock that have been linked to the western Irish Sea gyre. There is a smaller fishery in the eastern Irish Sea (~600 t landings and 150 t discards). Sampling is not as good but there is also a dedicated UWTV survey which is the main basis of the advice.

From a mixed fisheries perspective the main fishery in the Irish Sea is the *Nephrops* fishery and that has implications particularly for bycaught species. It is also important to factor in *Nephrops* in any multispecies models of the Irish Sea ecosystem. Studies in the past suggested that there has been an increase in the *Nephrops* populations due to reductions in natural mortality by cod in particular. Given the abundance of higher quality food such as sprat and herring it would be interesting to know if there is a trade-off between cod and *Nephrops* in reality.

3.4 Cod and haddock in the Irish Sea

Catches of cod have declined from more than 14 000 t in the last 1980s to less than 400 t in 2013. This declining trend is also observed in the spawning–stock biomass, which has declined tenfold since the late 1980s and has been considered to be well below B_{lim} at reduced reproductive capacity since the mid-1990s. Various management measures have been introduced in the Irish Sea in an attempt to reverse this declining trend and to shift the focus to stock recovery. These measures include seasonal closures to protect the adults during the spawning season, but mostly aimed at directly or indirectly reducing fishing mortality. Since 2003, the overall fishing effort has been reduced by more than a third in the Irish Sea, but more applicable to cod, the targeted whitefish TR1 (≥100 mm mesh sizes) effort has been reduced by more than 90% over this time period. Despite this the stock assessment still shows a severely depleted stock that has shown little or no response to the various management actions that have been initiated so far in an attempt to recover the stock.

Recruitment has been severely impeded since the late 1990s and has been very low for the past 13 years and below average for more than two decades. Slightly stronger year classes have been observer in 2009 and 2013. These higher recruitments suggest that there is some potential in the stock to produce higher recruitment, but that the stock–recruit dynamics may be different at lower stock size. Poor recruitment could of course also be climate/environment driven.

Assessment models fitted to the catch data assume that the decline in the cohort abundance results from fishing or natural mortality. Due to known bias with landings information from 2000–2005 and reliable discard estimates only available for the most recent years, the assessment model estimates a catch bias parameter since 2000. The model estimates of total losses or deaths are now estimated to be more than ten times the reported landings. Possible causes such as discards, emigration, survey bias and underreporting were examined by the ICES assessment EGs, but it remains difficult to reconcile the large apparent mortality rate and estimated unaccounted removals in recent years with the reduction in fishing effort by whitefish trawlers and the reduced catches as a result of quota and technical measures. The cod fishery had been reduced to a bycatch fishery with technical measures in place to assure that the cod catch to less than 1.5% of the total catch.

There have been a number of positive indicators in recent years, such as the high catch rates during the summer sentinel fishery (using commercial whitefish gear) and the high survey index in the 2015 quarter 1 fishery-science partnership survey (despite the timing of the survey being not optimal). However, despite the presence of large fish, the paucity of fish 5-years and older in any of the datasets, suggests continued high mortality. There is currently no evidence from the age compositions from numerous fishery-independent surveys or from the commercial fishery of any improvement in age structure that would result from a reduction in total mortality. Examining the mortality rate over the time period for which information is available (since 1968) shows that total mortality for the stock have been high throughout. Even when the stock was considered abundant and recruitment levels supported high levels of catch the gradient of the catch curve was in the range 0.8–1.0. Year classes rapidly disappeared from the commercial landings data through the time-series.

The time-series of haddock landings since the early 1900s indicated periodic high abundance period of haddock in the Irish Sea. The haddock stock increased rapidly in the mid 1990s from almost nothing, to a very lucrative fishery. The fishery targeting haddock was the same fishery that targeted cod. Whereas the relatively high fishing effort of the TR1 fishery in the 1990s preceded the dramatic decline in the cod stock, the haddock stock expanded under similar fishing pressure. The current period of high haddock abundance is the longest sustained period observed since the early 1900s.

Although the decline in cod stock is not observed in the haddock, there are a number of similar characteristics between these stocks. Length information from surveys in the first half of the 1900s indicates the size of haddock being very similar to what is being currently observed. Similar to cod, haddock grows to a large size (length and weight) demonstrating good condition, but shows the same paucity of 5-years and older fish. This truncated age structure from all source of information suggested high mortality rates for the stock. There is no evidence of an expansion of the age structure, despite reduced fishing linked to management measures imposed on cod and the large reduction in the TR1 effort.

The similarities of high mortality, a truncated age structure and more recently a reduction of maturity-at-length for cod, haddock and also whiting, suggested a possible influential ecosystem driver that affects all the commercial gadoid stocks in the Irish Sea. Similar characteristics being observed over the entire time period for which information is available also suggest influencing factors over and above that induced by fisheries or more recent climatic changes, which requires further investigation.

3.5 Overview of the Irish Sea sole stock

Scientific advice by ICES shows that the sole stock in the Irish Sea is in very poor state. This is in sharp contrast to the perception of the Belgian fishing industry as the lpue levels of the Belgian fleet were relatively constant and much higher than the survey. As such a science–fisheries partnership project was initiated in 2013 to investigate the status of the Irish Sea sole stock in more detail.

1) Analyses of commercial fishery

The Belgian fleet has been active on three fishing grounds in the Irish Sea for several decades:

- Cardigan Bay: target species is ray (catches of sole are negligible);
- Eastern Irish Sea (Liverpool Bay): the most important area for sole(use of alternative beam trawl gear);
- West and Middle Irish Sea (Horse shoe and Chicken): a mixed-species fishing ground.

Due to the reduction in fishing effort, the number of vessels that are active in the Irish Sea has strongly reduced. However Belgian VMS data (2006–2013) shows that despite this reduction the fleet is still as widely dispersed. This observation is in contrast to the expected concentrated and patchy dispersal pattern of an overfished stock.

In contrast to the survey, the sole lpue of the Belgian beam trawl fleet is relatively constant. However as the TAC declined by 53% in 2013, a sharp decrease was observed in their lpue. Hence the fishing behaviour of the fleet has changed. The effort in the Cardigan Bay (targeting ray exclusively) has doubled whereas in the Liverpool Bay, the effort has decreased by 50%. For the mid-Irish Sea the fishing effort remained constant in 2013 as they target other species besides sole.

The strong reduction of the quota in the Irish Sea makes it almost impossible for the Belgian fleet to continue fishing in the Irish Sea. This would lead to a major loss of relevant knowledge of the fisheries, and hamper the provision of high-quality science information on the status of the stock.

Until now, discard data (discard ratio <8%) has not been included in the assessment as their effect on the stock is minimum. However the commercial fisheries sampling data in 2013, showed that substantial discarding (14%) of juvenile sole took place in the Liverpool bay. Together with the increased lpue for sole in this area, this indicates a positive stock status trend.

2) Analyses of the UK-beam trawl survey

The UK-BTS-Q3 data are used to calculate the abundance index for the Irish Sea sole stock. For this purpose, catches of both juvenile and adult sole (up to age 7) caught on the station in the eastern Irish Sea are used. As part of the project a Belgian skipper experienced in the Irish Sea fishery and a scientist joined the survey. This collaboration raised some specific issues that need more investigation:

- In contrast to the commercial fleet, the survey catches a negligible number of adult (and juvenile) sole in the Mid Irish Sea fishing ground;
- Since 2000, the abundances of sole and plaice in the Eastern Irish Sea have shown opposing signals. Where sole is reduced, plaice is booming (confirmed with commercial discard data);
- Adult sole has become distributed more off shore in recent years. A similar distribution shift has been reported for other species like rays. What causes these distribution shifts?

3) Additional research

- Why are there contrasting lpue levels between the Belgian fleet and the survey, with a special focus on the mid-Irish Sea area?

- What is the influence of the wind farms on the recruitment success of sole as those windmills are located in the main spawning area for sole in the Irish Sea;
- Both the survey and the commercial fishery indicate a change in the seabed composition for the eastern part (more shelf material and sea star fish), which makes fishing at some survey stations difficult. Is this due to the reduction in fishing activity (less bottom trawling) or due to a change in the ecosystem?
- Continue the monitoring of the Belgian fleet to collect more age data, discard information, etc. to understand and quantify the changing fishing behaviour;
- Detailed analysis will be done on the survey data to look at alternative methods to calculate the abundance index;
- A campaign will be organized where a commercial vessel fishes next to the survey vessel to compare catch compositions.
- Seascape genetic research will be conducted on sole from the Irish Sea and Celtic Sea to investigate the distribution and migration pattern of sole. The aim is to investigate whether adult sole in the mid-Irish Sea originates from the one spawning ground in the Liverpool Bay or whether the sole is originating in the Celtic Sea. In case of the latter, additional research should assess the contribution of each spawning ground to the adult stock.

Although this project focuses on the Irish Sea sole stock in particular, the outcome can contribute to the understanding of the Irish Sea ecosystem and vice versa. In this context, ILVO is looking forward to collaborate in any possible way.

4 Management considerations

Changes over the past decade of the primary Irish Sea fisheries from gadoids to crustaceans highlight the importance in evaluating technical, societal, and economic trade-offs between fleets and sectors. Additionally these considerations should be addressed within the changing legislative framework such as the Landing Obligation.

4.1 Socio-economic aspects of integrated ecosystem assessments for the Irish Sea

The objective of this presentation was to highlight the importance of taking socio-economic aspects of the Irish Sea fishery into account in the formulation of integrated ecosystem assessments. A central tenet of ecosystem-based management is the inclusion of humans as part of the ecosystem (Curtin and Prellezo, 2010). As such, the economics of the primary industry of fish harvesting must be taken into account and the socio-economics of the activity, the social impact of the activity to coastal communities, must also be taken into account. Due to time constraints, this presentation was limited to analysing the Republic of Irelands' fleet activity in the Irish Sea, how dependent this fleet is on certain species, and their dependence on Irish Sea fisheries. Vessel landings were linked to the county of registration of the vessel owners and so county landings and revenue were estimated. Revenue generated was estimated using sales notes price data linked to the landings declarations.

Overall, landings from the Irish Sea are mainly composed of shellfish and pelagic fish. Excluding the sudden influx of sprat over the years then both landings and landing value are dominated by shellfish (including *Nephrops*). As noted earlier, *Nephrops* and scallop contribute two thirds of the total value of the region. The economic dependence of the entire Irish fleet targeting *Nephrops* on the Irish Sea *Nephrops* fishery is important but moderate at 23% for that species however dependence on Irish Sea scallops is high and increasing over time (63%). The smaller polyvalent general segments below 15 m landed the highest quantities of Irish Sea fish but these were mainly whelk, sprat and herring, both pelagic species being of low landing value. The larger polyvalent and specific vessels that land *Nephrops* and scallop contribute the lion's share of total landing value.

Fishers registered in Wexford land the highest quantities and generate the most value from their Irish Sea landings. The county has the most important specific and beam trawl fleet in the country with a sizeable polyvalent general segment also. Given its location on its southern edge of the Irish Sea the county depends on average below 40% on the Irish Sea for its total revenue however it is highly dependent on scallops. Within the Irish Sea Dublin and Louth fishers are highly economically dependent on the *Nephrops* fisheries (79% and 84% TI) however in terms of their total revenue Dublin fishers depend on the Irish Sea for ~60% of total income. Louth fishers on the other hand have less dependence on this area with ~25% of total revenue generated from the Irish Sea.

In terms of restrictive fisheries management measures on the Irish Sea *Nephrops* stock and their impact on coastal communities this would suggest that Dublin fishers would be more heavily impacted than their Louth counterparts who have more capacity to change grounds and exploit Celtic Sea *Nephrops* fisheries such as the Smalls or Labadie in the Celtic Sea or other *Nephrops* fisheries further away such as the Porcupine Bank or the Back of the Islands (VIIb). For such measures on the scallop fishery Wexford fishers would be most heavily affected however they do have potential to exploit nearby Celtic Sea fisheries.

Howth is the most important port in terms of landing quantity and value, with *Nephrops* and scallop dominating volumes and value. The port is 71% dependent on Irish Sea landings value. Landings of Irish Sea fish into Dunmore East is composed mainly of sprat and herring. The port is only 11% dependent on Irish Sea landings value. The value of Irish Sea landings into Kilmore Quay and Clogherhead are dominated by scallop (88%) and *Nephrops* (87%) respectively. These ports are dependent on Irish Sea landings value to the tune of 27% and 67% respectively.

Many avenues of further work on the socio-economic aspects of Irish Sea ecosystem advice exist, one salient avenue being an institutional analysis of Irish Sea fisheries management along with the management systems of other economic activities in the area. The institutions that exist here create the incentive structure under which all economic agents act and in the case of fisheries, national, European and international institutional arrangements are those that create the incentives that act as a force upon fishermen.

4.2 BIM gear trials in Irish *Nephrops* fisheries

Recent BIM trials have been driven by the need to provide options to fishermen for compliance with the Landing Obligation.

Discarding of smaller *Nephrops* and fish species are the issues that BIM have addressed in these trials.

The following measures have been evaluated to reduce discards of *Nephrops*:

> Codend mesh size. An increase in codend mesh size is the simplest technical measure to adopt in terms of cost and practicality. The results of the BIM 2015 western Irish Sea trial showed that increase in codend mesh size from 70 mm to 80 mm resulted in a 44.7% reduction by weight of *Nephrops* <25 mm CL.
>
> *Nephrops* sorting grids with 15 mm bar spacing. Very recent trials with 15 mm bar spacing *Nephrops* sorting grids have shown promising results. A report is being written at present and will be available on the BIM website shortly.
>
> Square mesh codends. Square mesh codends with stretched mesh sizes of 40, 50 and 60 mm will be evaluated in late 2016. Square mesh codends generally exhibit larger and more stable mesh opening angles and are likely to improve fish and *Nephrops* selectivity.

The following measures have been evaluated to reduce discards of fish:

> Quad-rigs. In comparative trials with twin rigs the quad rig caught 60% less cod, 38% less haddock and only 3% less whiting by weight. The Total Length of whiting observed during the trial was mainly <27 cm and this may explain why there were not larger reductions.
>
> A 300 mm Square Mesh Panel fitted 9–12 m from the cod line-caught 70% less haddock, 52% less whiting and 50% less cod. Cod catches amounted to 3 kg during the trial but work by Seafish UK in the same area has shown major reductions in cod catches.

300 mm SELTRA 4-panel sorting box. A recent Industry led trial with the SELTRA showed promising results. The trial found that optimizing the attachment point of the SELTRA is key in reducing *Nephrops* losses and maximizing selectivity for fish. Further trials may take place in 2016.

Swedish grid. The Swedish grid is the Fishing Industries least preferred gear modification. Practical handling concerns and losses of marketable fish are the major concerns. However, it is the technical measure that allows fishermen to target *Nephrops* with a bycatch of only fish small enough to pass through the 35 mm bar spacing. In Sweden the Swedish grid is required by law to fish near shore waters and it must be combined with a 70 mm square mesh codend to improve selectivity for small fish such as cod.

Square mesh codends. The previously mentioned trial of 40, 50 and 60 mm mesh size square mesh codends will also examine selectivity for smaller fish such as whiting, haddock and cod. The trial will take place in late 2015.

Results of BIM gear trials can be viewed at: http://www.bim.ie/our-publications/fisheries/

5 Conclusions

WKIrish1 was tasked with three Terms of reference, given below.

a) With stakeholders, scope the current challenges for advice provision for Irish Sea fisheries, and derive a list of management objectives that should be considered when exploring ecosystem based management of fisheries;

b) Identify potential tools, data and knowledge to investigate the challenges to fisheries management in the Irish Sea (including analysis of productivity changes, carrying capacity, multispecies models, and mixed fisheries approaches). These can be empirical, simulation or qualitative in nature. [The tools identified should be available for use throughout the following twelve months to explore the potential interactions of growth, selectivity and mortality on the dynamics of fish populations.]

c) Using the two ToRs above, develop a roadmap to generate the required scientific knowledge to support an ecosystem based fisheries management approach for the Irish Sea;

d) Identify intersessional work needed, including an action list of responsible people for each task to lead the intersessional work.

5.1 Scoping and management objectives

The meeting was attended by a wide range of scientists (both ecosystem and stock assessment), stakeholders (NWWAC-industry and NGO) and managers. The first broad conclusion was that the Irish Sea could be considered as a challenge for management as it was seen as relatively unique, for a number of reasons. The most obvious, and the stimulation for this series of workshops, is the remarkably high mortalities apparently experienced by the main fish species in the area. This is despite the considerable reductions in fishing pressure over recent years, particularly in the TR1 fleet. Combined with the highly truncated age structures shown by most of the commercially exploited species makes this area unusual.

As an ecosystem, the Irish Sea could also be seen as unique, at least within the ICES ecoregion and western waters more generally. It is a fairly closed ecosystem. Although it is open to the main Atlantic waters at both the North and South, the degree of linkage with them is unclear, with frontal systems at both openings. The main basin area (around the Isle of Man) is probably even more isolated, as the Northern Channel is relatively narrow, and blocked to some extent by the Islay Front. To the south there is a considerable area between Wales and Ireland before reaching the Irish Sea front. The idea of the Irish Sea as more like a lake than a sea, were expressed at the workshop, and also analogies to other relatively enclosed seas, such as the Baltic.

This conclusion was supported by a range of presentations detailed above. There is a considerable amount of data and information available on this region, but the challenge will be to integrate that, and to provide understandings that can inform management decisions.

Management objectives may be difficult to fully define at this time. Industry representatives pointed out that there are a range of management drivers including; the Landing Obligation, pressures to develop mixed fisheries plans and multiannual plans, and a need to move in future to consider multispecies interactions and dimensions. Other policy drivers include MSFD and maintaining or achieving GES. Other policy drivers will also need to be considered especially in the context of Marine Spatial Planning.

The current management objectives for the commercial fish stocks are clear and based on exploiting below F_{MSY} and maintaining stock levels above $B_{trigger}$. The key question is whether these objectives are attainable given the possibly unique ecology of the Irish Sea ecosystem.

Finally, the workshop all agreed that it would help the Process greatly if the stakeholders remain involved throughout. In particular, the stakeholders were very keen to participate in the specification of the trophic interactions, who eats whom, for the models, and then to be involved in the scenarios setting for simulations with the models once they are working.

5.2 Potential tools, data and knowledge

In terms of the potential tools the workshop agreed that a key requirement was to be able to develop models to address the questions in a multispecies and ideally whole ecosystem context. Two modelling approaches were identified; EcoPath with EcoSim - EwE) (see Section 2.4), and Multispecies fish community modelling (see Section 2.5). EwE has been widely used around the world to address similar fisheries and ecosystem management questions. An EwE model has been developed for the Irish Sea, but in a different context and would need modifications and updating. The multispecies fish community model approach has been applied in the North Sea (Thorpe *et al.*, 2015), and could be readily modified for the Irish Sea. Much of the data needed to populate these models are available, and indeed have been used in the previously developed EwE model for the Irish Sea (Lees and Mackinson, 2007). More recent EwE work at SAMS and at University College Cork can also be integrated. The approach would be to populate both models with up to date data and to compare the outcomes. Having two models available, with very different structures and methods, but using the same data wherever possible will help provide more robust conclusions. If the models agree on any of the conclusions it will tend to confirm those. If there is a mismatch it should demonstrate that we are looking at structural rather than parametric uncertainty.

An important element of the information for these models will come from the existing single-species stock assessments, and these should be updated within WKIrish 2 and 3. These should be carried out as best as possible within the current data constraints, even if they are not robust enough for advice provision, they would still be able to provide important inputs to the simulation phase of EwE.

On a wider ecosystem scale we would propose updating and improving the existing Irish Sea Ecosystem Description produced in the context of WGEAWESS (ICES, 2011 and 2013). This would be particularly at developing the specific linkages between ecosystem trends and the observed dynamics of the commercial fish populations. A part of this would include the approach to Integrated Trend Analysis detailed in Section 2.1. An additional component could come from the ODEMM based analysis carried out by the MI for the Irish Sea (Section 2.3) which with suitable wider expert inputs could be used to identify the main anthropogenic pressures on the ecosystem and their sources by sector.

A key source of knowledge would be to carry out a data archaeology for the fisheries of the Irish Sea, and particularly any evidence of historical patterns in age structure. If the type of truncated age structure noted in current stocks has been seen in the past, this might help explain why effort cuts have not been effective.

One possible explanation for the apparently high mortality would be emigration of the fish out of the management unit. Cod tagging studies suggest this may not be the case for that species, but little is known for whiting, haddock and plaice. One possible tool to study this would be to make use of C^{14} tracers. The Irish Sea is unusual in having high levels of C^{14} from the Sellafield nuclear power plant. This could give a unique signature for fish that were hatched and grew in the Irish Sea. If fish with that signature in their otoliths were also seen in the Celtic Sea or the west of Scotland, it would suggest emigration. A fuller mixed-stock analysis could then be carried out to determine the scale of this putative emigration. Similar genetic micro-satellite approaches may also be possible. These would be longer term studies as neither are cheap. However biological material would be readily available from otolith archives and biological sampling on surveys.

Finally, given the apparent reduction of weight-at-length for some of these populations, it may be valuable to explore the time-series of plankton from the CPR database.

5.3 Roadmap

Based on 5.1–5.2 above a roadmap for the WKIrish Process up to and after WKIrish3 is detailed below.

1) Single-species assessment models should be sorted out. (Whiting, cod, haddock, and plaice); WKIrish 2 and 3

- 1.1) Useful to have multispecies information later to test assumptions used in single species assessments.
  - 1.1.1) Recruitment, S–R relationships, environmental drivers of R
  - 1.1.2) Natural mortality, trophic interactions
  - 1.1.3) Truncated age structure

2) Develop Multispecies modelling capabilities

- 2.1) EwE (Sheila Heymans SAMS); Requires additional resources
  - 2.1.1) Initial model must be revised to look at basic structure, carry out the “key run” for further use in simulations
    - 2.1.1.1. Would include sprat, *Nephrops*, and other key ecosystem components, as well as the commercial fish
  - 2.1.2) Must address diet assumptions
    - 2.1.2.1. Expert / Stakeholder to build information into the model; to set up trophic interactions, hold a workshop with Stakeholders to do this, coincide with WGEAWESS 2016
- 2.2) Multispecies fish community model (Rob Thorpe Cefas). Has time assigned from Cefas
  - 2.2.1) Characterization of fleet dynamics and management units.
  - 2.2.2) Trophic interactions where possible from the same source and compatible with, the interactions used in EwE (above).

3) Document peculiarities of the Irish Sea; improve ecosystem description. What is different about the Irish Sea?

4) Document truncated age structure

- 4.1) Empirically identify presence of potential Irish Sea truncated age structure.

4.1.1) Is this recent, and if not how far can we trace it back??

4.2) Hypothesize why such severely truncated age structures are found particularly in this region, but for most of the species; explaining will provide credibility for advice.

4.2.1) Possible candidate explanations.

4.2.1.1. Fishing; usual suspect, but obvious first thing to check

4.2.1.2. Migration; if not dead, then may have simply left. May be possible to check with tagging, e.g. for cod, not really possible for whiting. Alternatives:

4.2.1.2.1. Sheila Heymans - C^{14} in Almost uniquely produced from Sellafield, so potentially reliable marker for Irish Sea fish outside the Irish Sea (Celtic Sea, west of Scotland); use otoliths from cod, whiting, and haddock outside the Irish Sea

4.2.1.3. Environmental caused increased natural mortality, e.g. increased natural predators, decreased food availability (scope for growth)

5) Zooplankton and lower trophic levels; Use CPR data from SAHFOS to examine changes in plankton community that may contribute. (e.g. *C. finmarchicus* vs. *C. helgolandicus*)

6) Develop the Irish Sea ODEMM analysis with appropriate scientific and stakeholder expertise, to, in particular determine which anthropogenic pressures (and from which sectors) are likely most important for the Irish Sea, and particularly for commercial fish stocks.

5.4 Identify intersessional work, action list and responsible people

The following should be possible to achieve in the time-scale and given that we succeed in sourcing funding for the EwE work.

- Single-species stock analyses; WKIrish 2 and 3.
- Build appropriate multispecies models
  - Multispecies fish community model; Robert Thorpe (Cefas)
  - EcoPath with EcoSim;- Sheila Heymans (SAMS)
    - Funding application to support this work; Sheila Heymans, Dave Reid, Steven Beggs
- Stakeholder workshop (trophic interactions) in collaboration with WGEAWESS and NWWAC (March and April, 2015); Dave Reid, Steven Beggs.

The following are desirable, but will depend on people and resources being available:

- Improved Irish Sea Ecosystem Description focused on commercial stocks. Dave Reid, Steven Beggs
- Document history of truncated age structures; WKIrish2 or possibly MI.
- Investigate emigration; Choose C^{14} or genetic methods, entirely dependent on additional funding.
- Plankton time-series; will depend on cooperation with SAHFOS

- Refine Irish Sea ODEMM analysis; depends on MI being able to find resources.

5.5 Priority List

1) Single-species assessment models should be sorted out. (Whiting, cod, plaice, and haddock)

1.1) Useful to have multispecies models to approve assumptions to put into single-species assessments.

1.1.1) Recruitment

1.1.2) Natural mortality

1.1.3) Truncated age structure

2) Develop decent MS modelling capabilities

2.1) EwE (Sheila)

2.1.1) Initial model must be revised just to look at basic structure

2.1.1.1. Sprat, *Nephrops*, and other key ecosystem components

2.1.2) Must address diet assumptions

2.1.2.1. Expert / Stakeholder to build information into the model; to set up trophic interactions (Dave), coincide with WGEAWESS 2016

2.2) Ensemble model (Robert)

2.2.1) Characterization of fleet dynamics and management units?

3) Document peculiarities of the Irish Sea; improve ecosystem description

4) Document truncated age structure

4.1) Empirically identify presence of potential Irish Sea truncated age structure.

4.2) Hypothesize why; explaining will provide credibility for advice.

4.2.1) Fishing

4.2.2) Migration

4.2.2.1. Sheila- C^{14} in otoliths from cod, whiting, and haddock outside the Irish Sea

4.2.3) Environmental caused increased natural mortality

5) Zooplankton and lower trophic levels; ask SAHFOS

6) ODEMM; add expert judgement to Irish Sea.

6 References

Alexander, K. A., J. J. Heymans, S. MaGill, M. Tomczak, S. Holmes, and T. A. Wilding. 2015. Investigating the recent decline in gadoid stocks in the west of Scotland shelf ecosystem using a food-web model. CES Journal of Marine Science 72:436–449.

Christensen, V. and C. J. Walters. 2004. EcoPath with EcoSim: methods, capabilities and limitations. Ecological Modelling 172:109–139.

Curtin, R., and Prellezo, R. 2010. Understanding marine ecosystem based management: A literature review. Marine Policy, 34(5), 821–830.

Diekmann R, Otto S, Möllmann C. 2012. Towards Integrated Ecosystem Assessments (IEAs) of the Baltic Sea: Investigating Ecosystem State and Historical Development. In: Climate Impacts on the Baltic Sea: From Science to Policy. Springer, p 161–199.

Gowen RJ, Hydes DJ, Mills DK, Stewart BM and others. 2002. Assessing Trends in Nutrient Concentrations in Coastal Shelf Seas: a Case Study in the Irish Sea. Estuarine, Coastal and Shelf Science 54:927–939.

Heymans, J. J., M. Coll, S. Libralato, L. Morissette, and V. Christensen. 2014. Global Patterns in Ecological Indicators of Marine Food Webs: A Modelling Approach. PLoS ONE 9:e95845.

Hyder, K., A. G. Rossberg, J. I. Allen, M. C. Austen, R. M. Barciela, J. Blanchard, M. T. Burrows, E. Defriez, T. Dorrington, K. Edwards, B. Garcia-Carreras, M. R. Heath, D. J. Hembury, J. J. Heymans, J. Holt, J. E. Houle, S. Jennings, S. Mackinson, R. McPike, L. Mee, D. K. Mills, C. Montgomery, D. Pearson, J. K. Pinnegar, M. Pollicino, E. E. Popova, L. Rae, S. I. Rogers, D. Speirs, M. Spence, R. Thorpe, R. K. Turner, J. van der Molen, A. Yool, and D. M. Paterson. 2015. Making modelling count - increasing the contribution of shelf-seas community and ecosystem models to policy development and management. Marine Policy 61:291–302.

Lees, K. and S. Mackinson. 2007. An EcoPath model of the Irish Sea: ecosystems properties and sensitivity analysis. Science Series Technical Report 138, Cefas, Lowestoft. Lynam CP, Lilley MKS, Bastian T, Doyle TK, Beggs SE, Hays GC (2011) Have jellyfish in the Irish Sea benefited from climate change and overfishing? Glob Change Biol 17:767–782.

Thorpe, R. B., W. J. F. Le Quesne, F. Luxford, J. S. Collie, and S. Jennings. 2015. Evaluation and management implications of uncertainty in a multispecies size-structured model of population and community responses to fishing, Methods in Ecology and Evolution, 6, 49–58. DOI 10.1111/2041-210X.12292.

Annex 1: List of participants

Name	E-mail	Institute
Barbara Schoute	schoute@bim.ie	NWWAC
Barrie Deas	barrie@nffo.org.uk	NFFO
Brendan Price	bmp.price@gmail.com	Irish Seal Sanctuary
Colm Lordan	colm.lordan@marine.ie	Marine Institute Ireland
Daragh Browne	browned@bim.ie	BIM
David Reid, Chair	david.reid@marine.ie	Marine Institute Ireland
Debbi Pedreschi	debbi.pedreschi@ucdconnect.ie	Marine Institute
Debbie Crockard	Debbie.Crockard@mcsuk.org	Marine Conservation Society
Emiel Broukaert	emiel.brouckaert@rederscentrale.be	Redersvereniging
Francis O'Donnell	ifpo@eircom.net	Irish Fish Producers Organization
Hugo Boyle	hugo.boyle@gmail.com	Irish South and East Fish Producers Organisation
John Lynch	jleblana@hotmail.com	Irish South and East Fish Producers Organisation
Leanne Llewellyn	Leanne.Llewellyn@wales.gsi.gov.uk	Welsh Government
Liane Veitch	lveitch@clientearth.org	ClientEarth
Michael Keatinge	keatinge@bim.ie	BIM
Mike Kaiser	oss405@bangor.ac.uk	Bangor
Norman Graham	norman.graham@marine.ie	Marine Institute Ireland
Pieter-Jan Schon	Pieter-jan.schon@afbini.gov.uk	AFBI
Richard Curtin	curtin@bim.ie	BIM
Robert Thorpe, Chair	robert.thorpe@cefas.co.uk	Cefas
Sam Shepard	s.shephard@qub.ac.uk	IFI
Sara Vandamme	s.g.vandamme@salford.ac.uk	University of Salford
Sarah Davie	sarah.davie@marine.ie	Marine Institute Ireland
Scott Large, Chair	scott.large@ices.dk	ICES
Shelia Heymans	sheila.heymans@sams.ac.uk	SAMS
Simon Dedman	simon.dedman@research.gmit.ie	GMIT
Sofie Nimmegeers	sofie.nimmegeers@ilvo.vlaanderen.be	ILVO

Annex 2: Agenda

WKIrish1-Workshop on the impact of ecosystem and environmental drivers on Irish Sea fisheries management

14 September–15 September 2015

Wilton Park House, Wilton Place, Dublin 2

Note: The Chairs aim for the workshop to be rich in discussion. To facilitate this, please keep presentations focused on the topic and limited to ~15 minutes. Presentations can be uploaded to the WKIrish1 SharePoint.

14 September

0930: Coffee and Tea

1000: Challenges for Irish Sea fisheries advice - Ecosystem presentations

1300: Lunch

1400: Challenges for Irish Sea fisheries advice - Fisheries presentations

1545: Coffee and Tea

1600: Challenges for Irish Sea fisheries advice - Management / regulation presentations

1800: Adjourn

1830: Reconvene for drinks

15 September

0900: Continue with uncovered topics from Day 1

1045: Coffee and Tea

1100: Establish priority list for both ecosystem and fisheries work

1300: Lunch

1400: Roadmap and Intersessional work - how to initiate collaborations

1600: Adjourn / Coffee and Tea

Annex 3: WKIrish1 Terms of Reference

The Workshop on the impact of ecosystem and environmental drivers on Irish Sea fisheries management (WKIrish1), chaired by Robert Thorpe, UK; David Reid, Ireland and Scott Large, Denmark, will be established and will meet in Dublin, Ireland, 14–15 September 2015.

The workshop (WKIrish1) will initiate an 18 month process to develop the evidence of ecosystem-based management for fisheries in the Irish Sea. The management of Irish Sea fisheries is currently challenged by a lack of recovery in some fish populations (cod, whiting and sole) despite large reductions in fishing effort. Total mortality remains very high for gadoid stocks in the Irish Sea. There have also been significant changes in growth rates, productivity and maturity for various species.

The WKIrish process will be driven by the objective of disentangling which potential drivers (ecosystem and/or environmental) are important to consider when developing management plans for Irish Sea fisheries.

This first workshop will:

With stakeholders, scope the current challenges for advice provision for Irish Sea fisheries, and derive a list of management objectives that should be considered when exploring ecosystem based management of fisheries;

Identify potential tools, data and knowledge to investigate the challenges to fisheries management in the Irish Sea (including analysis of productivity changes, carrying capacity, multispecies models, and mixed fisheries approaches). These can be empirical, simulation or qualitative in nature. [The tools identified should be available for use throughout the following 12 months to explore the potential interactions of growth, selectivity and mortality on the dynamics of fish populations.]

Using the two ToRs above, develop a roadmap to generate the required scientific knowledge to support an ecosystem based fisheries management approach for the Irish Sea;

Identify intersessional work needed, including an action list of responsible people for each task to lead the intersessional work.

WKIrish1 will report by 15th October 2015 for the attention of ACOM and SCICOM.

Supporting information

Priority	The current activities of this workshop are in line with the ICES strategic plan to progress towards integrated ecosystem assessments.
Scientific justification	At the ICES WGCHAIRS 2015 meeting the scope of the Irish Sea Benchmark was extensively discussed. It was agreed that the Irish Sea would be a good test bed for ICES to develop an integrated ecosystem benchmark. The fisheries components to the ecosystem are relatively well understood. Several recent projects have looked at ecosystem models and reviewed the Irish Sea ecosystem in general. What has been missing thus far is how we integrate these new types of information and data into and improve the current stock assessments and management advice. Irish Sea fisheries have changed from a cod, whiting and herring dominated fishery in the 1960s to one which is dominated by *Nephrops* and other shellfish stocks today. Since the early 2000s, ICES has been advising zero catch for cod and whiting. Despite strong effort reductions and other measures to recover the cod stock, there is little evidence of any stock response, suggesting ecosystem aspects (e.g. various sources of natural mortality) may be playing a role. The work plan for WKIrish is a 2-year process, and focuses on improving single-species stock assessments (principally cod, haddock, whiting, plaice, herring), incorporating a mixed fisheries model, and developing the integration of ecosystem aspects and working towards an integrated assessment and advice. There is a strong link PGDATA to develop guidelines for data compliation and evaluation. There are four main workshops, but work needs to be coordinated and progressed intersessionally. The four workshops address: WKIrish1 (September 2015): Information sharing and scoping; WKIrish2 (November/December 2015): Data compilation; WKIrish3 (February/March 2016): Stock assessment benchmark; WKIrish4 (October 2016): Towards development of an integrated ecosystem assessment and advice. It would be beneficial to identify co-chairs for the whole process, which could, but must not necessarily also co-chair the workshops
Resource requirements	The research programmes which provide the main input to this group are already underway.
Participants	Experts on integrated assessment, fish stock assessment models and Irish Sea ecosystem, stakeholders (industry, administrations, NGOs).
Secretariat facilities	Professional assistance by the ICES Secretariat.
Financial	No financial implications.
Linkages to advisory committee	There are close links with ACOM and SCICOM.
Linkages to other committees or groups	ACOM/SCICOM Benchmarking Steering Group (BSG), ACOM/SCICOM Steering Group of Integrated Assessments (SSGIEA), ACOM/SCICOM Steering Group on Integrated Ecosystem Observation and Monitoring (SSGIEOM), WGCSE, HAWG, WGEF, PGDATA, WGEAWESS, BEWG, WGZE, WGMME, WGSFD, WGSAM, WGMIXFISH, WGISUR, WGECO, WGBIOP
Linkages to other organizations	NWWAC, OSPAR

Annex 4: Outline of feedback from stakeholders

- Stakeholder 1:
  - Within industry and AC-frustration that management measures have failed for more than a decade to recover demersal stocks. Meanwhile, within the context of Northeast Atlantic and the Common Fisheries Policy, the general trends have been positive, a reduction of F to sustainable levels. Irish Sea has bucked the trends. The industry and AC welcome a solution and a need to put fisheries management within an ecosystem context. Ecosystem impact fisheries and vice versa.
  - Hopeful the meeting / process will generate something of use, which must take into account the context in which decisions are made.
  - E.g. Landing Obligation, pressures to develop mixed fisheries plans, multiannual plans, multispecies interactions and dimensions, legal and political imperative.
  - Need to develop approaches that meet GES.
  - Impression of WKIrish1-positive view of scoping meeting, allows us to identify process where the answers might be, it will be helpful.
    - Good to get everything out onto the table is a good place to start. Broad influences on fish stocks and fisheries, whether it be climate, hydrography, phytoplankton, and exploring the reasons for poor recruitment.
    - Having credible explanations for these issues is important.
    - Big ecosystem changes and we can anticipate big changes in future. Important to take into account within the design of our approach.
    - Useful cutting edge research to identify the best way forward.
    - Examining assumptions that underpin assessments and management decisions - in particular natural mortality, is important.
  - Major themes-
    - Fishing effort has been cut by 50%. TR1 has been reduced by a factor of ten, and yet there still is no recovery that we would otherwise anticipate.
    - Factors affecting recruitment (regime shift)
    - Truncated age structure for cod, haddock, and whiting. Which appear to have persisted over decades. Is this an unaccounted source of mortality or is it emigration? Without a handle on this we won't be able to answer the questions.
    - Reduction of maturity-at-length.
    - Natural mortality and the availability of zooplankton on important life stages.
  - Irish Sea was described as a lake, which seems to be significant. Overlapping fisheries, spawning grounds, multiple fisheries, and multiple uses
  - Should take lessons from North Sea, Baltic, Celtic Sea, Newfoundland, and other areas and apply these to Irish Sea.
    - Identify differences; species interactions, etc.

  - Biological and behavioural aspects-may have anomalies within assessment that might be important to consider.
  - Hard part is to point the way forward.
  - Useful initiative that it is to be hoped breaks us out of a cycle of ignorance and failure.
  - How will the stakeholders remain involved over the next 18 months?

- WK Chair response:
  - Important to retain stakeholders throughout.
  - EBFM-is a two way process, in addition, fisheries affecting ecosystem that has affected the fisheries back.
    - Regime shift partially caused by fishing pressure on the ecosystem.

- Stakeholder 2:
  - Relative newcomer to the area.
  - Clearly a complicated situation and we don't fully understand the dynamics. Enough understanding to at least get started. Which represents the purpose of WKIrish.
  - In terms of fisheries-Some affects are caused by things that we can't influence, environment, and others we can, fishing and other human dynamics.
    - Do we need to increase marine spatial planning? Perhaps it is because of the additional human activities within crucial areas?
    - Build in additional activities within spatial models.
  - Limitations and benefits of moving towards multispecies advice. Important to keep it within the context of the legal framework and also trying to communicate the risks and benefits of takin an MS approach so decision-makers and stakeholders understand the implications of one choice over another from a suite of options. Will increase transparency of decision-making and increase acceptance and buy in
  - Data collection and whether we can collect additional data in more efficient and useful ways without duplication efforts. So we can maximize our return on data collection resources.

- WK Chair response:
  - Important aspect- marine spatial planning.

- Stakeholder 3:
  - Truncated age structure-may be an exception to this, sole.
  - Multispecies advice-where are we with this? Is it on the way?

- WK Chair response:
  - Depends; it is living longer, however, still not as long as in areas. Still relatively truncated in both short and long-lived species.

- Multispecies modelling will be a useful for this, and multispecies information will be used to fit into single-species management advice.

- WK Participant:
  - Building blocks must be to nail the single-stock assessment models. Other stocks have fallen off the horse with full analytical assessments. Haddock, cod, whiting, and plaice need full analytical assessments. MSY Ranges for category 1 and 3 stocks will provide more info for this which can be used within mixed fisheries advice. Framework is set up in Celtic Seas and North Sea with F_{cubed}. Since only TR2 is the main fleet, the rush to mixed fisheries advice has been slower.

- Stakeholder 4:
  - Recovery-the perception of fishermen is that cod has recovered in the Irish Sea and we are able to handle a TR1, but there is a problem with the assessments
    - "Recovered" because they're catching two boxes per hour.
    - Unaccounted mortality rate is causing problems.
      - Mismatch between what catches and removals are, and total mortality in the assessment. No matter what we do to the data in the stock assessment, it can't match the two boxes an hour.
    - Tend to congregate in an area where there is a highly intensive *Nephrops* fishery. Stock rebuilding has seemed too accelerated in the last three years.
    - A pity the recovery couldn't be recovered in the scientific data. Anecdotal information of what the fisheries is seeing, isn't captured in scientific data
  - What type of advice needs to come out of this to populate multiannual plans?