ICES WGSAM REPORT 2015

SCICOM STEERING GROUP ON ECOSYSTEM PRESSURES AND IMPACTS

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Report of the Working Group on Multispecies Assessment Methods (WGSAM)

9–13 November 2015

Woods Hole, USA

ICES
International Council for the Exploration of the Sea

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Contents

Executive summary

Three meetings were held between 2013 and 2015 (Stockholm, London and Woods Hole). WGSAM has been making significant contributions required to enable ICES to develop its capability to give advice on the ecosystem impacts of fishing and climate change. This is a priority area identified in the ICES strategic plan and is consistent with scientific needs to support implementation of the Common Fisheries Policy and Marine Strategy Framework Directive.

A particularly important development has been the guidelines on quality assurance of ecosystem models intended for advice giving. WGSAM prepared a briefing on this issue and continues to work on issues related to model review processes, model validation and developing methods for generating advice from multi-model ensembles. WGSAM also produced a series of briefing sheets, one for each multispecies model, describing the approaches and capabilities of each model and thus serve as a resource for re-searchers inside and outside seeking to understand multispecies models.

WGSAM executed key runs for the North Sea (SMS in 2014 and Ecopath with Ecosim in 2015). WGSAM also worked with WGMIXFISH to identify joint prioritises for further developments.

1 Administrative details

Working Group name

Working Group on Multispecies Assessment Methods (WGSAM)

Year of Appointment within the current three-year cycle

2013

Reporting year concluding the current three-year cycle

2015

Chair(s)

Steven Mackinson, UK

Daniel Howell, Norway

Meeting venue(s) and dates

Stockholm, Sweden, 21–25 October 2013 (12 participants)

London, UK, 20–24 October 2014 (13 participants)

Woods Hole, USA, 9–13 November 2015 (22 participants)

2 Terms of Reference

ToR A. Report on further progress and key updates in multispecies and ecosystem modelling throughout the ICES region

ToR B. Report on the development of key-runs (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (including the Baltic EwE 2013, Barents Sea 2014, North Sea EwE 2014, North Sea SMS 2014, Baltic Sea SMS 2015 and others as appropriate)

ToR C. Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs)

ToR D. Develop and compare foodweb and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO)

ToR E. Report on progress on including new stomach samples in the ICES area in multispecies models.

ToR F. Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points)

ToR G. Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM)

ToR H. Work towards providing ecosystem advice consistent with species and technical interaction in mixed fisheries (preferably together with WGMIXFISH)

3 Summary of Work plan

Summary of the original Work Plan

Member contributions to any of the ToRs will be accepted in any year, but where possible, effort will be made to focus WG activities on particular ToRs as proposed below:

YEAR	WORK
Year 1	Work on all ToRs. Tor B restricted to Baltic EwE. Focus on D, E, G
Year 2	Work on all ToRs. Tor B restricted to Barents Sea Gadget, North Sea EwE 2014 and North Sea SMS. Focus on B, C, H
Year 3	Work on all ToRs. Tor B restricted to Baltic Sea SMS. Focus on F, H

4 Summary of Achievements of the WG during 3-year term

1) Briefing to SCICOM and ACOM on a proposed process for evaluating and verifying the suitability of a new multispecies model for providing inputs into management advice, and the subsequent evaluation of a specific key run of that model for a particular Ecoregion (2013).

2) A series of briefing sheets, one for each multispecies model, describing the approaches and capabilities of each model and thus serve as a resource for researchers inside and outside seeking to understand multispecies models (2013).

3) Key Run of the North Sea Stochastic Multispecies Model (SMS) (2014, finalised 2015)

4) Key Run of the Ecopath with Ecosim North Sea ecosystem model (2015)

5) Report on Joint meeting with WGMIXFISH to further understanding of the links between the two groups work and identify future priorities which support development of ICES advice on multi-species and mixed fishery issues (2014).

6) Scientific papers addressing issues defined in WGSAM Terms of Reference.

5 Final report on ToRs, workplan and Science Implementation Plan

Progress and fulfilment by ToR

ToR A. Report on further progress and key updates in multispecies and ecosystem modelling throughout the ICES region

- Yearly reporting current progress of multispecies models and predator-prey research in ICES Ecoregions, noting in particular:

- Continued development of existing established modelling approaches such as Stochastic Multispecies Model,Gadget, Ecopath with Ecosim.
- Progress made with the development of ATLANTIS ecosystem models in the North Sea, Baltic Sea, Eastern Channel and Barents and Norwegian Seas.
- The surge in development and application of new multi-species length-based or size spectra models.

ToR B. Report on the development of key-runs (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (including the Baltic EwE 2013, Barents Sea 2014, North Sea EwE 2014, North Sea SMS 2014, Baltic Sea SMS 2015 and others as appropriate)

- Key Run of the North Sea Stochastic Multispecies Model (SMS) (2014, finalised 2015)
- Key Run of the Ecopath with Ecosim North Sea ecosystem model (2015)

ToR C. Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs)

- Established a process for the evaluation multispecies models and the criteria and standards considered necessary to make them acceptable for use in developing multispecies advice for management within ICES. Developed this into a specific briefing for ICES SCICOM and ACOM, leading to involvement in benchmark working group. To support this process and series of model briefing sheets was established (2013). Refinements to this processes were reported in Annex 6 of the 2015 report, indicating the importance of Key Run models in future developments of multi-model ensembles intended for advice.
- Defined what constitutes a Key Run of the SMS model and the Le Mans length based ecosystem model.
- Outlined suggestions for selection criteria for multi-model ensembles for use in advice and discuss how output from different models can be usefully combined for ensemble-type provision of advice. This will be built upon in ToRs 2016–2018.
- Expert input on methods for evaluating the performance of multispecies models in a systematic way (2015).

ToR D. Develop and compare foodweb and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO)

- Used WGECO criteria in applying their expert judgement to score the utility of proposed ecosystem indicators, this being fed back to WGECO.

- Science papers incorporating MSFD indicators in evaluation of the performance of MSY objectives (see Science highlights).

ToR E. Report on progress on including new stomach samples in the ICES area in multispecies models.

- Reported on Baltic and North Sea stomach sampling projects and the Cefas-DAPSTOM database, which now has record in excess of 200 000 and is harmonized with the ICES 'Year of the Stomach' databases.
- Re-iterated the need for regular stomach sampling to ensure that multi species and ecosystem models remain relevant for advice on fisheries assessments and MSFD GES descriptor 4 regarding the structure and functioning of foodwebs.
- Reviewed recent information on the prey of cod in the Barents Sea (2015).

ToR F. Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points)

See 2013 report and 2015 contributions

- An overview of the current state-of-the-art in ICES for using multispecies modelling to give insights into MSY, the implications of a changing environment and its relevance to practical management advice on ecological and fishery trade-offs. In particular, work on the long-term implications of moving from current management to multispecies MSY, and the need to take account of the implications of model uncertainty and the utility of different community indicators (see WGSAM 2013, 2015).

ToR G. Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM)

- Highlighted the importance of spatial structure in models and summary of recent work in the North Sea and Barents Sea (WGSAM 2013).

ToR H. Work towards providing ecosystem advice consistent with species and technical interaction in mixed fisheries (preferably together with WGMIXFISH)

- WGSAM and WGMIXFISH held a joint workshop in London on 23rd October 2014. Outcomes were WGMIXFISH undertook a principle component analysis (PCA) on the métier data used by the group, to see how many aggregated fleets resulted and to show how the variance in catch composition changes with different levels of fleet aggregation. (WGSAM 2014).

Science highlights

Papers and reports published by WGSAM members in the period 2013–2015 and directly relevant to the WG ToRs:

Alexander, Karen A; Heymans, Johanna J; Magill, Shona; Tomczak, Maciej T; Holmes, Steven J; Wilding, Thomas A; .2014 Investigating the recent decline in gadoid stocks in the west of Scotland shelf ecosystem using a foodweb model ICES Journal of Marine Science: Journal du Conseil . fsu149

Anon 2014. Report of the Expert Workshop to Review the Japanese JARPA II Special Permit Research Programme. IWC. Tokyo. 24–28 February 2014.

Anon 2015. Report of the Expert Panel to Review the NEWREP Special Permit Proposal. IWC. Tokyo. 6–10 February 2015.

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Cormon X, Ernande B, Kempf A, Vermard Y, Marchal P (2016) North Sea saithe Pollachius virens growth in relation to food availability, density dependence and temperature. Mar Ecol Prog Ser. 542:141–151, DOI:10.3354/meps11559.

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Gårdmark, Anna; Lindegren, Martin; Neuenfeldt, Stefan; Blenckner, Thorsten; Heikinheimo, Outi; Müller-Karulis, Bärbel; Niiranen, Susa; Tomczak, Maciej T; Aro, Eero; Wikström, Anders; .2013 Biological ensemble modelling to evaluate potential futures of living marine resources Ecological Applications 23.4 742–754

Holmgren N. M. A., N. Norrström, R. Aps, and S. Kuikka. 2014. A Concept of Bayesian Regulation in Fisheries Management. PLOS One, 9 (11): e111614. doi:10.1371/journal.pone. 0111614

Hornborg S., Belgrano A., Bartolino V., Valentinsson D., Ziegler F. 2013. Mean trophic level and primary production required in Swedish fisheries over a century: possibilities and limitations of the indicators. Biol. Lett. 9: 20121050.

Howell 2014. Center for Independent Experts (CIE) Peer Review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the California Current Large Marine Ecosystem

Howell, D., and Filin, A.A. 2013. Modelling the likely impacts of climate-driven changes in cod-capelin overlap in the Barents Sea doi: 10.1093/icesjms/fst172

Howell, D., Hansen, C., Bogstad, B., and Skern-Mauritzen M. 2016. Balanced harvesting in a variable and uncertain world – a case study from the Barents Sea. ICES Journal of Marine Science. In press

ICES 2013. Report of the Baltic Fisheries Assessment Working Group (WGBFAS), 10 - 17 April 2013, ICES Headquarters, Copenhagen. ICES CM 2013/ACOM:10. 738 pp.

ICES 2013. Report of the Benchmark Workshop on Baltic Multispecies Assessments (WKBALT 2013). 4–8 February 2013, Copenhagen, Denmark. ICES CM 2013/ACOM:43.

ICES 2013. Report of the Benchmark Workshop on Baltic Multispecies Assessments (WKBALT), 4–8 February 2013, Copenhagen, Denmark. ICES CM 2013/ACOM:43. 201 pp.

ICES 2013. Report of the Inter-Benchmark Protocol for Herring in Subdivision 30 (IBP Her30), 11–15 March 2013, By correspondence. ICES CM 2013/ACOM:60. 94 pp.

ICES. 2014. Report of the Baltic Fisheries Assessment Working Group (WGBFAS), 3–10 April 2014, ICES HQ, Copenhagen, Denmark. ICES CM 2014/ACOM:10. 834 pp.

ICES. 2015. Report of the Baltic Fisheries Assessment Working Group (WGBFAS), 14–21 April 2015, ICES HQ, Copenhagen, Denmark. ICES CM 2015/ACOM:10. 826 pp.

ICES. 2015. Report of the Benchmark Workshop on Baltic Cod Stocks (WKBALTCOD), 2–6 March 2015, Rostock, Germany. ICES CM 2015/ACOM:35. 172 pp.

ICES. 2015. Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB), 9–13 March 2015, Cádiz, Spain. ICES CM 2015/SSGIEA:08. 30 pp.

Julia L. Blanchard1*, Ken H. Andersen2, Finlay Scott3,4, Niels T. Hintzen5, Gerjan Piet5 and Simon Jennings3,6. Evaluating targets and trade-offs among fisheries and conservation objectives using a multispecies size spectrum model. Journal of Applied Ecology 2014 doi: 10.1111/1365–2664.12238

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Lehuta, Sigrid, Stephanie Mahevas, Pascal Le Floc'h, et Pierre Petitgas. A Simulation-Based Approach to Assess Sensitivity and Robustness of Fisheries Management Indicators for the Pelagic Fishery in the Bay of Biscay ». Canadian Journal of Fisheries and Aquatic Sciences 70, nº 12 (décembre 2013): 1741-56. doi:10.1139/cjfas-2013–0066.

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Mackinson, S. 2014. Combined analyses reveal environmentally driven changes in the North Sea ecosystem and raise questions regarding what makes an ecosystem model's performance credible? Canadian Journal of Fisheries and Aquatic Sciences, 2014, 71(1): 31–46, 10.1139/cjfas-2013–0173

Metcalfe, K., Vaz, S., Engelhard, G.H., Villanueva, M.C.,Smith, R.J. and Mackinson, S. 2015. Evaluating conservation and fisheries management strategies by linking spatial prioritization software and ecosystem and fisheries modelling tools of Applied Ecology 2015 doi: 10.1111/1365–2664.12404

MYFISH deliverable report 2.3 Decision Support Table demonstrating the effects of aiming at different MSY variants on indicators: Decision Support Table demonstrating the effects of aiming at different MSY variants on indicators of yield and ecosystem, economic and social aspects in each region.

Neuenfeldt, Stefan; Gårdmark, Anna; Muller-Karulis, Barbel; Hinrichsen, Hans Harald; Möllmann, Christian; Uusitalo, Laura; Holmgren, Noel; Norrström, Niclas; Large, Scott; Tomczak, Maciej; .2015 Short-term prediction and harvest control rules for Baltic cod (Gadus morhua): A generic method to include state of the art knowledge on environmental uncertainty and its consequences–would it make a difference for advice? ICES Annual Science Conference 2015 .

Nielsen, J Rasmus; Thunberg, E; Schmidt, JO; Holland, Dan; Bastardie, Francois; Andersen, JL; Bartelings, Heleen; Bertignac, M; Bethke, E; Buckworth, R; .2015 Evaluation of integrated ecological-economic models–Review and challenges for implementation ICES Annual Science Conference 2015 .

Niiranen, Susa; Yletyinen, Johanna; Tomczak, Maciej T; Blenckner, Thorsten; Hjerne, Olle; MacKenzie, Brian R; Müller-Karulis, Bärbel; Neumann, Thomas; Meier, HE; .2013 Combined effects of global climate change and regional ecosystem drivers on an exploited marine food web Global change biology 19.11 3327–3342

Olsen E, Fay G, Gaichas S, Gamble R, Lucey S, and Link JS. 2016. Ecosystem model skill assessment: Yes we can! PLoS One 11(1): e0146467. doi:10.1371/journal.pone.0146467

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Pinnegar, John K; Tomczak, Maciej T; Link, Jason S; .2014 How to determine the likely indirect food-web consequences of a newly introduced non-native species: A worked example Ecological Modelling 272. 379–387.

Pope, J.G. 2015. An interactive multispecies model of the North Sea suitable for stakeholders and managers to use to interpret multispecies and mixed fishery issues and their biological, economic, social and EAFM trade-offs. ICES CM 2015/A:03

Pope, J.G. 2015. Development of methods based around the un-centred moments of the population length distribution for multispecies assessments of marine fisheries. ICES CM 2015/A:23

Romagnoni, G., Mackinson, S, Hong, J. and Eikeset, A-M. 2015. The Ecospace model applied to the North Sea: evaluating spatial predictions with fish biomass and fishing effort data (Journal of Ecological Modelling) Ecological Modelling (2015), pp. 50–60 DOI information: 10.1016/j.ecolmodel.2014.12.016

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Tiselius, P., Belgrano, A., Andersson, L., Lindahl, O. 2015. Primary productivity in a coastal ecosystem: a trophic perspective on a long-term time-series. J. Plankton Res., 1–11.

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6 Cooperation

- **Cooperation with other WG**
  - WGECO – definition of food web indicators
  - WGMIXFISH – joint session 2014 on mixed fisheries issues in multi-species models
  - ICES Benchmark Steering Group – model acceptance procedures
  - WGHAWG – provided advice on natural mortality in different ecoregions. Natural mortalities for stock assessment, and multispecies considerations advice
  - WGNSSK – natural mortalities for stock assessment, and multispecies considerations advice
  - WGIMM – model matrices tables review
  - WGBIOP – support development and QA of new biological parameters
  - WGDIM – discuss structure of stomach database
  - WGBFAS – natural mortalities for stock assessment, and multispecies considerations advice
  - WGBIFS – provide manual for stomach sampling
  - IBTSWG – provide manual for stomach sampling

- **Cooperation with Advisory structures**
  - ACOM
  - SCICOM

7 Summary of Working Group self-evaluation and conclusions

WGSAM continues to do provide a forum for developing the approaches, methods and tools to support ICES in providing integrated, ecosystem-based advice.

This report summarises the achievements of the group in the last 3 years, the details of which are documented in three reports covering the meetings in 2013–2015.

The self-evaluation form highlights that more should be done to better integrate the groups' advice-relevant outputs in to the ICES advisory system. This is particularly important to address now given the proposed ToRs for 2016–2018 (particularly ToR g) and their relationship to the commitments made in the CFP and the MSFD to implementation of the ecosystem approach to management.

Annex 1: List of participants

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Annex 2: Agenda

ICES Working Group on Multispecies Assessment Methods (WGSAM)

Woods Hole, USA, 9–13 November 2015

Date	What and Who
Monday	• Agree Agenda and confirm contributions from participants **AM** **ToR A. Report on further progress and key updates in multispecies and ecosystem modelling throughout the ICES region.** **Presentations** 1. Celtic Sea LeMans model (Rob Thorpe) 2. WGBIOP relevance to WGSAM (Harriet Cole) 3. Food web model (NDND) of the Barents Sea (Ulf Lindstrom) 4. MSI-SOM of the Baltic (Noel Holmgren) **PM** ToRC. Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs) • Update on WGSAM work on model acceptance procedure and how it feeds in to the Benchmark SG and model validation procedures. (Daniel Howell, Sigrid Lehuta) • In 2015 the group will discuss and outline suggestions for selection criteria for multi-model ensembles for use in advice and discuss how output from different models can be usefully combined for ensemble-type provision of advice. This will be built upon in future years. (Rob Thorpe?) • Sarah Gaichas- preliminary results from multispecies model performance testing that could be used in discussions on selection criteria for building multimodel ensembles (we are testing a production model now and should have a delay difference model to compare it with by then). • Model performance evaluation (Sigrid Lehuta)
Tuesday	**AM** **ToR B. Report on the development of key-runs (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (North Sea EwE 2015, Baltic Sea SMS 2015 and others as appropriate)**

	• Baltic Sea SMS Key Run– (Morten Vinther) – discuss data etc and pick up later in week • North Sea EwE Key Run (Clement Garcia and Steve Mackinson) – present and discuss) **PM**: Work on ToRs A, **B** and Requests (see table below) **ToR F Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points)** Presentations 1. Multispecies consequences of ICES MSY ranges (Rob Thorpe) 2. Reconciling MSY and GES in the North Sea, under a changing environment (Mackinson, time permitting)
Wednesday	**AM** **Brief considerations of (pending any specific contributions) :** ToR D. Develop and compare food web and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO) ToR E. Report on progress on including new stomach samples in the ICES area in multispecies models **PM** **Food-dependent growth workshop? (See Appendix 1)**
Thursday	**AM** ToR G. Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM) Pick up on Key Runs **ToR H: Work towards providing ecosystem advice consistent with species and technical interaction in mixed fisheries.** **Presentations** 1. Multi-species and mixed fishery models use in evaluating North Sea MAP options. … and comments on other MAP evaluations for Meditteranean and NWW. Where are we at? (Mackinson, Jan Jap, Eider and anyone others) 2. Outline of proposal to commission call on MAPs (Jan Jap) 3. Sarah Gaichas - 10 species, 3 mixed fleets model looking at tradeoffs in yield and biomass 4. Multispecies interactions in an idealised 4 fleet North Sea fishery (Rob Thorpe).

	PM Work on Report
Friday	• Reflect on ToRs and tweak where necessary. • Nominate and select new Chairs • Define new multiannual ToRs • Decide date and location WGSAM 2016 • Work on Report • Aim to finish by 13:30

Annex 3: WGSAM self-evaluation and draft multi-annual resolution 2016–2018

Copy of the WG Self-Evaluation

1) Name: **Working Group on Multispecies Assessment Methods (WGSAM)**

2) Yes of appointment: **2013**

3) Current Chairs: Steven Mackinson (UK) and Daniel Howell (Norway)

4) Venues and dates:

4.1) Stockholm, Sweden, 21–25 October 2013 (12 participants)

4.2) London, UK, 20–24 October 2014 (13 participants)

4.3) Woods Hole, USA, 9–13 November 2015 (22 participants)

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

WGSAM members conduct and publish research on multispecies and multi-fisheries interaction and thus their work is closely linked with the two ICES science goals and their specific activities, specifically in order of priority:

Goal 2 Understand the relationship between human activities and marine ecosystems, estimate pressures and impacts, and develop science-based, sustainable pathways

- developing integrated ecosystem assessment methodologies and approaches that allow the use of both qualitative and quantitative data, and which can be used to address both specific advisory questions and broader ecosystem issues;
- providing tools and methods for assessing the relationships between marine ecosystems, their biological resources, and the provision of services (particulary food security) to society, including socio- economic aspects;

Goal 1 Develop an integrated, interdisciplinary understanding of the structure, dynamics, and the resilience and response of marine ecosystems to change

- investigating the structure, functioning, dynamics, and interconnectedness of marine ecosystems, their different biotic components, and the abiotic environment at different spatial scales;

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. *

Papers and reports published by WGSAM members in the period 2013–2015 and directly relevant to the WG ToRs

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7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

- The SMS key runs for the Baltic and the North Sea provide M2 values critical for the stock assessments in these areas.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from

the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

- Collaborations in EU H2020 project proposals (various) catalysed through the network opportunities afforded by WGSAM, but no specific project arising from WG discussions.
- Workshop: Building scenarios of future marine ecosystems under a global change context: moving forward. 8–10 June 2015, Sète, France.
- Reviews of ecosystem modelling programmes in the USA. (Atlantis review)
- The EU project "Myfish" on maximum sustainable yield is closely related to, and arises from work within, WGSAM
- Work presented and refined at WGSAM has been presented in a variety of fora (e.g. ICES ASC, American Fisheries Society, Internal Research Institute presentations).

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

- Not major difficulties, but we foresee that the possibility of a growing demand for evaluation of new models and their applications as Key Runs could become a heavy draw which impacts the broader work of WGSAM.

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)

Yes.

Reasons:

- **M2 values from key runs are an essential component of stock advice in the North Sea and the Baltic.**
- Article 9 of the CFP specifically Article 9,3b on multiannual plans which states "Multiannual plans shall cover: in the case of mixed fisheries **or where the dynamics of stocks relate to one another, fisheries exploiting several stocks in a relevant geographical area, taking into account knowledge about the interactions between fish stocks, fisheries and marine ecosystems".**
- The MSFD, particularly GES descriptor 3 Food Webs, requires information on how biological and fishery interactions affect the functioning of food webs and the consequences for ecosystem and its capability for provisioning services.
- Policy in other ICES jurisdictions (including the USA and Norway) also commits to adoption of ecosystem approach and the development of relevant methodologies to implement this.
- The work of WGSAM is intimately linked to the ICES Strategic Plan goal 3 on sustainable use: "Scientific information is the foundation of ICES advice and this advice must meet the needs of decision-makers. ICES will continue to deliver evidence- based scientific advice on environmental is-

sues and fishery management. **ICES is committed to transition, where appropriate, from single-species fisheries advice to advice in a mixed fishery, multispecies, and ecosystem context.** ICES will also develop regional integrated advice based on ecosystem assessments including indicators for assessing ecosystem status, and for the management of human activities.

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

N/A

(*If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat*.)

12) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToRs?

- Continuation of the wide range of multispecies experience and expertise is critical. In addition cooperation with other WGs (e.g. WGMIXFISH, WGECO) should be extended.

13) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)

- In addition to the current use of key runs to provide M2 values, these models (preferably as ensembles where multiple models occur for a region) should be used to provide advice on the possible ecosystem effects of MSY policy and of changes to specific targets/ management reference points. This could include both effects on stocks, fisheries and ecosystem indicators.

WGSAM draft multi-annual resolution 2016–2018

The **Working Group on Multispecies Assessment Methods** (WGSAM), chaired by Sarah Gaichas, USA and Daniel Howell, Norway (year 1), then Sarah Gaichas, USA and Alexander Kempf, Germany (year 2&3), will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2016	10–14 October	Iceland	Interim report by 1 December to SSGEPI	
Year 2017	TBA	TBA	Interim report by DATE to SSGEPI	**Change of Co-Chair**: Outgoing: Daniel Howell Incoming: Alexander Kempf
Year 2018	TBA	TBA	Final report two months after the meeting to SCICOM	

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	Review **further progress** and deliver key updates in multispecies and ecosystem modelling throughout the ICES region	This ToR acts to increase the speed of communication of new results across the ICES area	11, 22	3 years	Report on further progress and key updates for internal use in WGSAM as well as externally.
b	Update of **key-runs** (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and ecosystem models for different ICES regions	The key runs provide information on natural mortality for inclusion in various single species assessments	10, 15	3 years	Report on output of multispecies models including stock biomass and numbers and natural mortalities for use by single species assessment groups and external users.
c	Consider methods to assess the skill of multispecies models intended for operational advice.	This work is aimed assessing the performance of key runs focussing on natural mortality estimates and the ability to forecast population dynamics in comparison to standard single species forecasts.	15, 22	3 years	Report on methods contributing to Key run standards for use under ToR b and externally.
d	Investigate the performance of multi-model ensemble in comparison to single model approach.	The purpose of the work is to investigate whether the multi-model average out performs the single models.	15, 22	3 years	Report on the performance of multi model ensembles for selected case studies, including (i) a summary of the pros and cons applying multi-model ensembles, (ii) guidelines how to use output from multi-model ensembles for advice
e	Test performance and sensitivity of ecosystem	Ecosystem indicators are increasingly in	9	3 years	Report on the feedback on

	indicators.	use in ecosystem assessments, and require testing through modelling studies. With connection to WGECO.			proposed ecosystem indicators and suggestion of alternatives
f	Metanalysis of impact of top predators on fish stocks in ICES waters.	Pick up on work on marine mammals conducted in 2012. Extend to top-predators in general.	6	3 years	Report on the impact of top-predators on fish stocks in ICES waters.
g	Explore the consequence of multispecies, mixed fisheries interactions and environmental factors in practical multispecies advice for fisheries management (**MSY related and other biological reference points**)	Multispecies reference points such as those related to MSY in mixed fisheries and the effect of environmental changes on these reference points is a key point in multispecies/integrated advice. Connection to ICES-PICES climate change group. Connection to WGMIXFISH.	14, 15	3 years	Report on methods to include mixed fisheries and environmental considerations in multispecies advice and evaluations of trade offs between management objectives. Uncertainties in models will beclearly communicated.

Summary of the Work Plan

Member contributions to any of the ToRs will be accepted in any year, but where possible, effort will be made to focus WG activities on particular ToRs as proposed below:

Year	Work
Year 1	Work on all ToRs. Focus on ToR e, f and g. ToR b: Keyruns (as required)
Year 2	Work on all tors. Focus on ToR c and d. ToR b: Keyruns (North Sea SMS, as required)
Year 3	Work on all tors. Focus on Synthesis ToR c-g. ToR b: Keyruns (as required)

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the ecosystem effects of fisheries, especially with regard to the application of the MSY Approach. The activities will provide information (e.g., natural mortality estimates, performance of indicators) and tools (e.g., multi-model ensembles, keyrun models) valuable for the implementation of an integrated advice in several North Atlantic ecosystems. Consequently, these activities are considered to have a very high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. Depending on the requirements for advice, additional resource might be required

Participants	Approx 20. Expertise in ecosystem, modelling and fish stock assessment from across the whole ICES region.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	ACOM, most assessment Expert Groups
Linkages to other committees or groups	WGMIXFISH, WGDIM, WGBIFS, IBTSWG, WGECO, WGINOSE, WGIAB, WGNARS, WGIPEM, most EGs in the Regional Seas Programme.
Linkages to other organizations	None.

Annex 4: Detailed report from the 2015 meeting

1. Summary and introduction

Summary

In this ninth report of the pan-regional Working Group on Multispecies Assessment Methods (WGSAM), work focused on three (B, F, H) of the multi-annual ToRs.

Based on their knowledge, participants provided an updated inventory of progress of multispecies models in ICES Ecoregions (ToR A), noting those regions where no information was available. Reporting on ToR A was scarce compared to previous years, partly because recent relevant work was reported against ToR F and H instead.

A new Key Run (ToR B) of the North Sea Ecopath with Ecosim (NS-EwE) model was presented and reviewed in detail by 4 WGSAM experts, and approved by the group following implementation of changes agreed in plenary at the meeting and verified by the 4 experts in January. The Key Run is documented in a detail in Annex 6, with key outputs summarised in Section 3 and data files made available on the WGSAM webpage). In particular, a comparison of estimates of Fmsy ranges from multispecies and single species models for North Sea stocks is provided (see ToR B section 3). Following corrections made to the North Sea Stochastic Multispecies Model (NS-SMS) Key Run published in WGSAM 2015, the changes were reviewed and approved (ToR B section 3). Details of the expert review process for Key Runs is described in Section 3 and Annex 6.

Regarding ToR C, the proposed mechanism for accepting new multispecies models into the ICES advice giving process developed during the previous meeting (WGSAM 2013) has been submitted to ICES for consideration, but no formal response has been received. The newly formed Benchmark Steering Group is scheduled to discuss the WGSAM proposal and give a recommendation.

ToR F presented modelling work from a number of ecosystems relating to multispecies MSY fisheries. In the California Coast Current a part of ongoing work using multiple models (Atlantis, MICE model, Ecopath) to investigate multispecies fisheries interactions was presented, showing that the results were sensitive to assumptions about how flexible predators were in moving to exploit changing food resources. As such responses are difficult to model in advance, this represents a major source of uncertainty in attempting to model multispecies fisheries systems. In the Baltic an exploratory Nash Equilibrium optimisation approach was presented for the cod-herring-sprat fishery to attempt to identify a solution that would give good yield for all species simultaneously. Although the work was considered preliminary, it identified possible equilibria points for both constant F or constant biomass fisheries scenarios. In the North Sea a theoretical analysis using 4 "idealized" fleets was presented to analyse the potential implications of MSY ranges. The model examined the likelihood of the fishery being precautionary for the different species given the uncertainties involved, and concluded that the MSY ranges would not guarantee precautionarity, and in fact produce less precautionary outcomes than the recent single species MSY values. Finally, a new Gadget multispecies model for the Flemish Cap was presented, showing the strong interactions between cod, redfish and shrimp, which have each been sequentially at high abundances, but not simultane-

ously. The model was able to capture the changing balance between fishing and predation mortalities over the time-series, and could be a precursor to multispecies management of these strongly interacting stocks.

Work was presented in ToR H from the east coast of the US, showing a tool for evaluating the tradeoffs between management options, yield and stock status. The tool could identify management solutions that produced overall "good" results for yield and preserving stock status across the system – and could also highlight the tradeoffs involved for different fleet sectors between different management options. The tool is seen as part of ongoing communication with stakeholders. In the North Sea a theoretical analysis using 4 "idealized" fleets was presented to analyse the tradeoffs involved in a multispecies mixed fishery. It was demonstrated that there is a tension between yield and risk, and that such tools could be used not only for making the tradeoffs between different objectives and different fleets clear, but also for evaluating the utility of indicators as a proxy for ecosystem considerations in applied management. The Large Fish Indicator was examined, and shown to have variable utility in measuring the impact of different fleet sectors. Also in the North Sea, analysis was presented showing that much of the variability in the mixed fisheries could be captured by combining the metiers into around 10 categories, which could be a manageable number for incorporation into multispecies models. However it was stressed that it is not clear the extent to which mixed fisheries patterns will change as a result of the discard ban in the North Sea, and thus further work on the topic has been put on hold until such trends are clarified.

In addition, a workshop on modelling prey-dependent growth was held. Multispecies modelling research has focussed heavily on predation as a source of mortality in prey species, but less progress has been made in modelling the effects of varying consumption on the predators. This workshop brought together researchers from multispecies modelling, "extended single species" modelling and whole ecosystem ("end2end") modelling. A range of presentations, and a subsequent discussion, covered this from a theoretical and practical perspective. On the theoretical side there were presentations covering the current state of the art, and why parameterising such models is problematic. On the more pragmatic side were examples of approximating the impact on predators without fully simulating the predator-prey interactions. Although this is clearly an important topic, it is also one which is in the early stages of development.

New chairs were appointed: Sarah Gaichas, USA (2016–2018), Daniel Howell, Norway (2016), Alexander Kempf, Germany (2017/2018).

Opening of the meeting

The **Working Group on Multispecies Assessment Methods** (WGSAM) met in Woods Hole, USA, 9–13 November 2015. The list of participants and contact details are given in Annex 1. The Terms of Reference for the meeting were discussed, and a plan of action was adopted with individuals providing presentations on particular issues and allocated separate tasks to begin work on all ToRs.

Acknowledgements

WGSAM would like to thank Sarah Gaichas, Robert Gamble for logistics during the meeting and Maria Lifentseva of the ICES Secretariat for her continued support with the WGSAM SharePoint site.

Terms of reference

Focus was set on ToRs B, F, H (in bold).

ToR A. Review further progress and report on key updates in multispecies and ecosystem modelling throughout the ICES region;

ToR B. Report on the development of key-runs (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (North Sea SMS 2015, and fix of North SMS 2014).

ToR C. Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs)

ToR D. Develop and compare food web and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO)

ToR E. Report on progress on including new stomach samples in the ICES area in multispecies models

ToR F. Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points).

ToR G. Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM)

ToR H. Work towards providing ecosystem advice consistent with species and technical interactions in mixed fisheries (in connection with WGMIXFISH).

2. ToR A: Review further progress in multispecies and ecosystem modelling throughout the ICES region

The review of progress of multispecies models in ICES Ecoregions given below is not intended to be comprehensive and exhaustive. It reflects the knowledge available to the participants at the meeting and input from WGSAM who were not able to attend in person.

There was no participation from Russia or Canada at this year's meeting, and consequently no update on modelling from the regions.

2.1. Ecoregion A: Greenland and Iceland Seas

There is no progress to report on multispecies modelling in this Ecoregion this year.

2.2. Ecoregion B: Barents Sea

2.2.1. Predation by cod

Over a decade of moderate fishing pressure, combined with two good year classes (2004 and 2005) and favourable climatic conditions have led to high stock size and recovering age structure in the Barents Sea cod. Older cod are known to be more piscivorous, and the Barents Sea therefore presents a case study for how much more piscivorous. The stomach sampling scheme collect around 10 000 cod stomachs annually (split age 1–11+, by 3 areas and by half year), and we therefore now have a dataset of stomach samples from large (over 80cm) cod to analyse. Cod diet can divided into "large fish" (cod, polar cod, haddock, herring, Greenland halibut, long rough dab and redfish), capelin (the key forage fish) and other food (invertebrates and plankton). Between age 7 and age 9+ the proportion of large fish in the diet increases from 15% to almost 30% (Figure 2.2.1). The capelin consumption remains similar (around 40%), and the invertebrates and other food go down. The large cod remain cannibalistic, but can target a greater variety of cod sizes, and cannibalism therefore also increases. Although big cod remain a small fraction by number of the stock, they represent an important source of predation by biomass. The doubling of consumption therefore has important consequences for understanding and modelling multispecies interactions and ecosystems.

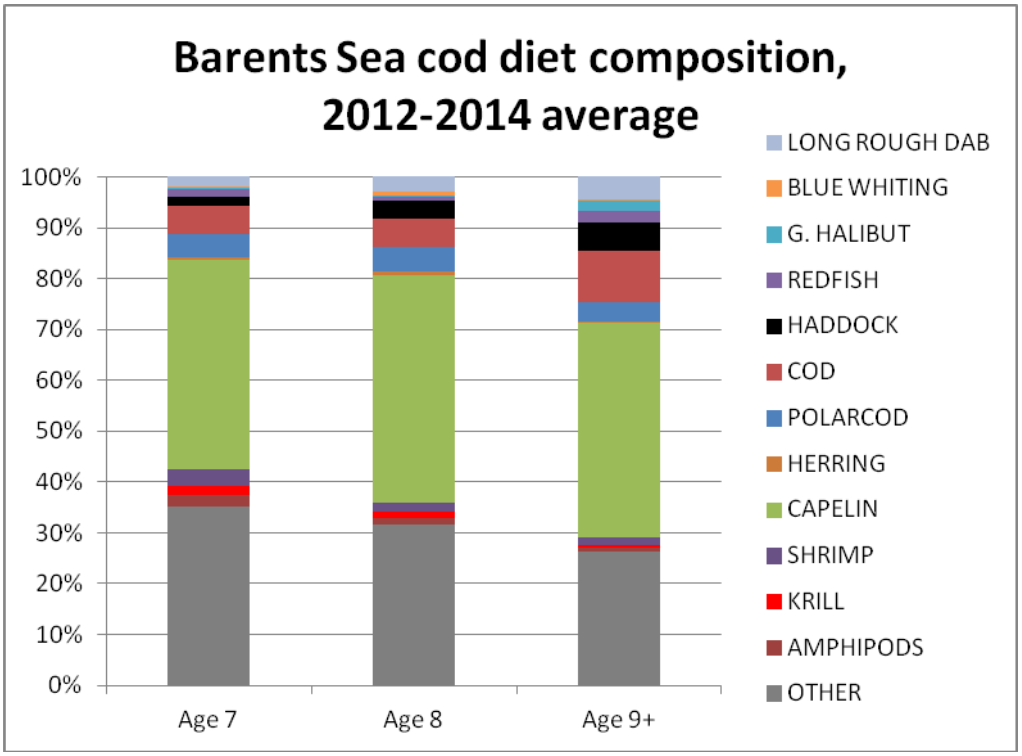

Figure 2.2.1a. Average prey proportions by species in the stomach samples of cod of age 7,8, and 9+ in 2012–2014 in the Barents Sea.

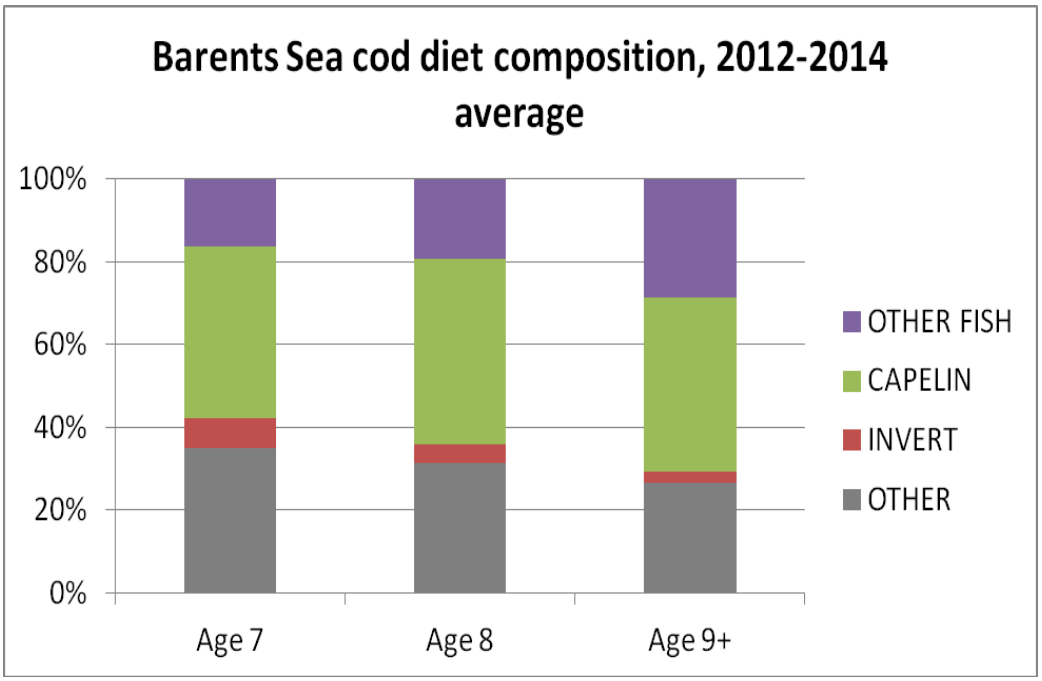

Figure 2.2.1b. Average prey proportions in the stomach samples of cod of age 7,8, and 9+ in 2012–2014 in the Barents Sea, divided into categories.

2.2.2. Cod, capelin, minke whale competition

Cod, harp seal and minke whale are the main top predators in the Barents Sea ecosystem. In the last decade, the abundance of cod has increased considerably, and is at a record high level. In spite of this, the growth and condition of cod has remained rather stable, although some decrease is seen in size at age of large, mature cod. During the same period, the abundance of harp seals has declined whereas the minke whale stock has been at a stable level. The body condition (blubber thickness) of these two mammal stocks has, however, decreased, with the strongest decrease observed for harp seals. A possible hypothesis for explaining this is that cod outperform the marine mammal stocks in the competition for food. The main advantages for cod are most likely larger availability of food (mainly capelin) during winter-spring than for marine mammals, as well as a wider range of prey species being available to cod than to marine mammals. Harp seals are more dependent on prey items found close to the ice edge than the other two predator stocks are, which could partly explain why the performance of harp seals is worse than that of the two other main top predators in the area.

2.2.3. Foodweb modelling

Understanding and predicting the patterns arising from the complex dynamics of marine food webs is central to trophic and community ecology. A parsimonious stochastic model, the Non Deterministic Network Dynamics (NDND, Planque *et al.* 2014), is used to simulate the Barents Sea food web dynamics (Lindstrøm *et al.* in prep). The NDND is a mass balance model with stationary food web structure, random trophic interactions, and a small set of physical and biological constraints. To evaluate the NDND model simulations are compared with a suite if food web patterns observed empirically during the

past 28 years: food web biomass and fluxes, biomass variability patterns, growth and density dependence, trophic controls, temporal stability, synchrony and consumer-resource functional responses. The results suggest that the NDND model can reproduce most of these patterns without requiring a complex model structure or deterministic trophic functional responses. Thus many of the patterns observed empirically in the Barents Sea can be interpreted as resulting from random trophic interactions operating within constraints set by a few ecological rules. The NDND model can provide a null model for expected patterns of food web dynamics in the Barents Sea, and thus, provide envelopes for the possible future states and trajectories-of-change of ecosystem properties.

2.3. Ecoregion C: Faroes

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.4. Ecoregion D: Norwegian Sea

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.5. Ecoregion E: Celtic Seas

2.5.1. Ecopath in the Celtic Sea

Work on modelling the Celtic Sea continues under the MERP programme in a collaboration with Cefas and Dr Lauria (Plymouth University) continues. The Ecopath model has been updated and hindcast simulations have been fitted to data on stock biomasses and catches. Using the fitted Ecosim model a spatial (Ecopsace) model is being calibrated using detailed data on the distribution of biological groups and fishing activity. A report is in preparation. It is intended that calibrated spatial model will be presented to ICES WGSAM as a Key Run, with the spatial fitting process used to help define Key Run standards for Ecospace applications.

Other initiatives to work on Ecospace modelling in the Celtic Sea and Bay of Biscay region are being established by Didier Gascuel at Agrocampus Ouest, France, and a collaboration is being sought.

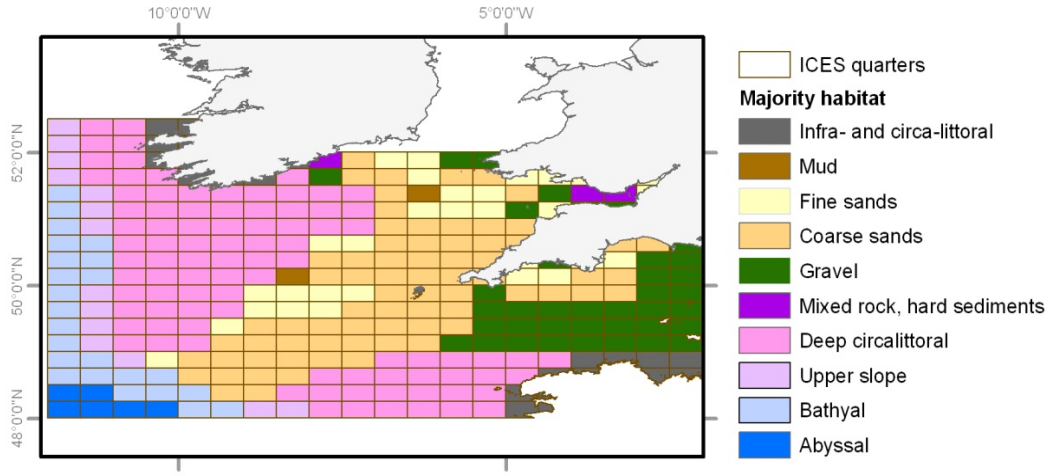

Figure 2.5.1. Habitat definition for Ecospace model of the Celtic Sea being developed by Cefas and Valentina Lauria. Habitats are defined by a combination of simplified sea bed sediments derived from the BGS 250k data set and biozones from UKSeaMap 2010, expressed as majority habitat at the resolution of the ICES quarter-rectangle.

2.5.2. Ecopath in the Irish Sea

No progress updates from 2014 received.

2.6. Ecoregion F: North Sea

2.6.1. Moment-based delay difference model in the North Sea

Dr John Pope was unable to attend the meeting but forwarded presentation relating to work done in the MAREFRAME project 'An interactive multispecies model of the North Sea suitable for stakeholders use'. The presentation is available on the SharePoint.

2.6.2. SMS (Stochastic Multispecies Model) in the North Sea

See ToR B.

2.6.3. Ecopath with Ecosim in the North Sea

See ToR B – new Key Run

The North Sea EwE was used in an STECF evaluation of proposed options for a multiannual plans for North Sea mixed demersal fisheries (STECF 2015). The model includes 68 biological groups and 12 fishing fleets with associated economic data on costs and prices from the EU 2008 Annual Economic Report (EU 2008). The main questions addressed was "What are the consequences of achieving, by 2016 and by 2020, fishing mortalities within the F_{MSY} ranges provided by ICES, with particular emphasis on the stocks of cod, haddock, whiting, saithe, sole, plaice and *Nephrops*?"

Simulations using the newly developed (Cefas) Management Strategy Evaluation routine in EwE highlighted the trade-offs among fleets and how indirect biological interactions

affected the yield and value trade-offs among fleets. A particular example being how the interactions among cod and nephrops affect fishery yield and value (Figure 2.6.1).

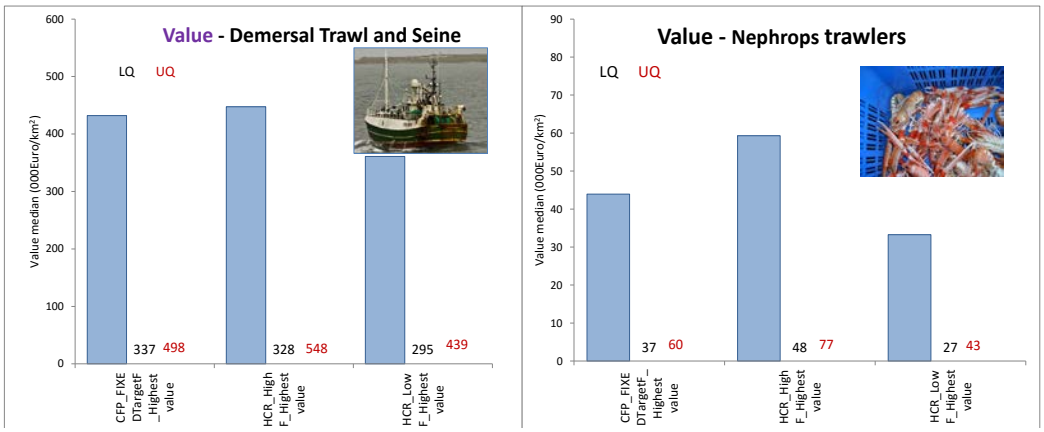

Figure 2.6.1. Long term (after 30 years) landed values for 2 selected fleets. Median values from 213 plausible predictions of the model, along with lower and upper quartiles.

2.6.4. Ecopath with Ecosim for the southern part of the North Sea

A southern North Sea Ecopath with Ecosim (EwE) has been finalized at the Thünen Insitute of Sea Fisheries to a fitted and calibrated stage. An application in identifying multispecies MSY and good environmental status (GES) for the food-web has been submitted to Ecological Modelling (Stäbler, Kempf *et al.* 2014 and 2015), including the model description and its parameterization in the appendix of the manuscript. In the manuscript, we exposed trade-offs between the fleets' objectives and explored, what a possible variant of a multispecies MSY could look like by subjecting the modelled system to a range of different fishing effort levels of the three main fleets (Otter, beam, and brown shrimp trawlers). Long-term projections highlighted multiple fishing regimes that lead to catches of at least 30% of all focal single species MSYs at the same time. Higher simultaneous yields of all four focus species (cod, plaice, sole and brown shrimp) could not be achieved, such that we can assume a risk for the southern North Sea's fisheries that multispecies 'pretty good yields' might fail. Key to the intuitively unsatisfying results are trade-offs between the yields of shrimp fishers and demersal trawlers, where brown shrimp so significantly benefit from reduction of its predators cod and whiting, that maximum catches of the shrimp are only achieved when cod are overfished and the yields to the otter trawlers thus much lower than they could be at 'healthier' cod stocks.

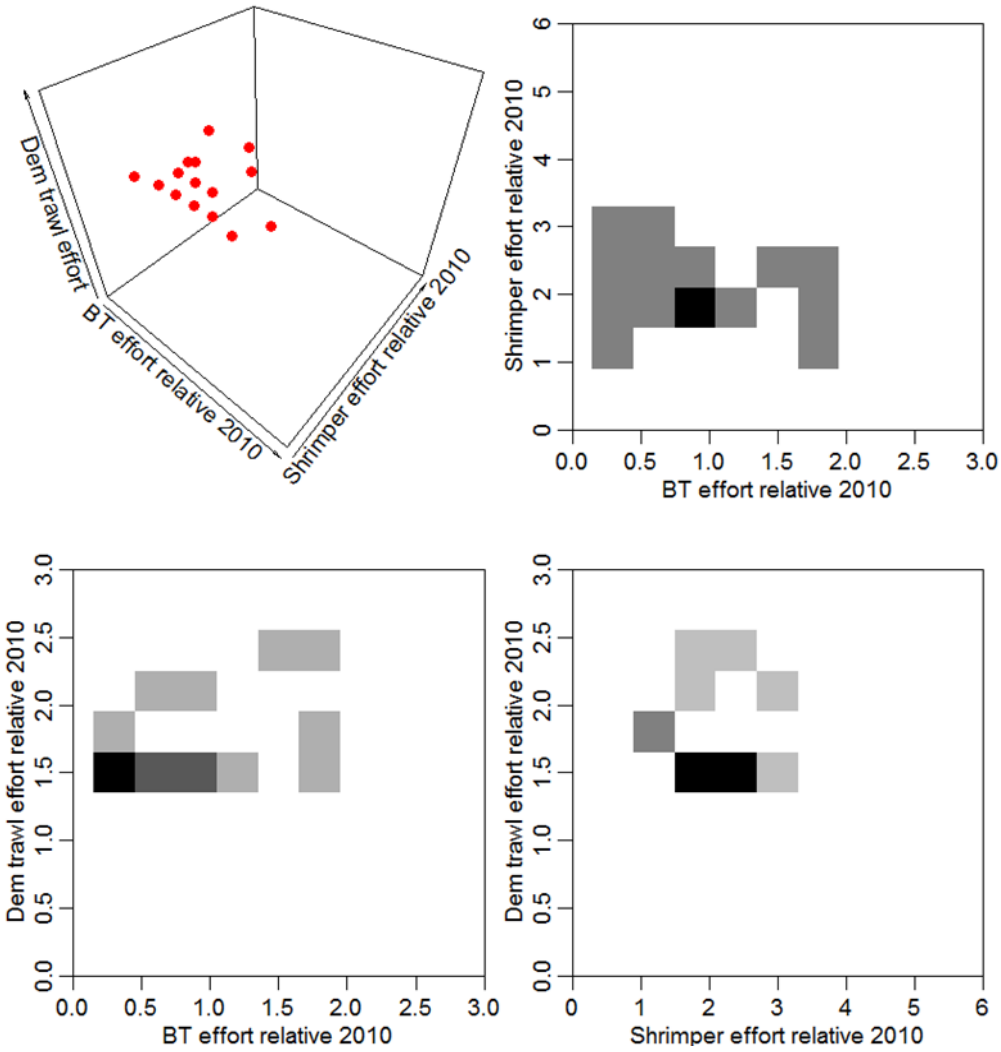

Figure 2.6.2. Spheres indicate effort regimes that lead to all four scope species — cod, plaice, sole and brown shrimp – to be simultaneously caught at 30% of their respective maximal possible catches.

Besides optimizing multispecies catches, we identified effort regimes that satisfied a set of descriptors of good environmental status (GES). We found that GES can only be obtained through low efforts of beam and demersal trawlers, which cannot be aligned with our multispecies MSY variant without accepting trade-offs in fishing yields and/or conservation goals.

Current efforts involving the southern North Sea EwE model include identifying the impact of density-dependent changes of catchability on effort at MSY and the associated impact these shifts in effort can have on bycatch species and the food-web.

2.6.5. Ecopath with Ecosim in the Eastern Channel

A presentation was made on the eastern English Channel EwE model. Future work perspectives include the improvement of the initial model developed by M.C. Villanueva (IFREMER) in 2006 and integrate recent stomach and stable isotope (Kopp *et al.* 2015) analyses data. The spatial analyses will go beyond the recent study made by Metcalfe *et al.* (2015) which investigated the potential trade-offs associated with adopting different spatially explicit MPA management strategies where Marxan and EwE software package was used. Spatial trophic studies will be based on the impacts of cumulative anthropogenic activities on ecosystem responses. Chl A result runs from a hydrodynamic model, MARS3D (Dumas and Langlois 2009), will be used to run spatial simulations in ECOSPACE.

2.7. Ecoregion G: South European Atlantic Shelf

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.8. Ecoregion H: Western Mediterranean Sea

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.9. Ecoregion I: Adriatic–Ionian Seas

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.10. Ecoregion J: Aegean–Levantine

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.11. Ecoregion K: Oceanic northeast Atlantic

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.12. Ecoregion L: Baltic Sea

Progress in the Ecoregion is reported under ToRs F and H.

2.13. Ecoregion M: Black Sea

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.14. Ecoregion: Canadian Northwest Atlantic

There is no progress to report on multispecies modelling in the Ecoregion this year.

2.15. Ecoregion: US Northwest Atlantic

Accounting for species interactions in both stock assessment modelling and fisheries management is of increasing interest in the Northeast US. Multiple models are in development in the region to address changing climate and species interactions. This has also involved considerable investment in generalized tool development (see the detailed paragraph below on Rpath). Multispecies assessment models in development require testing to evaluate their capabilities. Under ToR C we review progress on the ongoing Georges

Bank multispecies assessment project, which incorporates multispecies production models and multispecies delay difference models as assessment models within a multi-model inference framework and compares estimation from multispecies production and statistical catch at age models. Under ToR H we review simulations examining potential ecosystem, aggregate species, and species level status determination criteria. Further review of progress in the region is presented as part of the report on the prey-dependent growth workshop.

Sean Lucey presented an update on software of potential interest to the group. Sean Lucey, Kerim Aydin, and Sarah Gaichas (US, NOAA) have been working to develop an R package that implements Ecopath with Ecosim, tentatively named "Rpath". This tool will complement and expand on the open source possibilities of EwE, taking advantage of the existing statistical and graphical capabilities of R. Other advantages to developing the code in R is to encourage more community development, create a cross-platform software that works on operating systems other than Windows, and increase reproducibility of EwE models. Increased reproducibility stems from having all of your parameters and procedures contained in one script rather than as a series of button presses on a GUI. The software is working especially well for the static mass balance portion (Ecopath) and is working comparably to Ecosim now that one undocumented default EwE setting has been set the same in the R software. Rpath includes the "multistanza" age structured dynamics in Ecosim. The software is now entering the beta-testing phase with a workshop scheduled for early December in Seattle. A paper documenting the software and associated CRAN package is expected to be submitted for review within a month. To date, most interest in the package has been from advanced users as it is designed to accommodate simulations using hundreds to thousands of different parameterizations, which is not practical in the current EwE software. Questions raised at the meeting included whether a Shiny package had been considered for a GUI interface (not yet); whether the food web and time-series images shown are part of the package (yes, as summary plot objects); and whether this could interface with the FLR package (perhaps, will look into it).

Additional progress in the Ecoregion is reported under ToRs F and H.

2.16. Ecoregion: Southern Shelf Seas

Different ecosystem/multispecies modelling exercises continue in the Bay of Biscay and Iberian waters ecoregion, in the framework of different EU and regional projects.

Gadget single – and multi–species models

Different single species Gadget models are also been developed in the area for commercial fish species such as hake, anchovy, mackerel and horse mackerel. Linking these single-species models and re-optimizing all the parameters from a multi-species perspective, accounting also for the influences of the environmental variables in the dynamics of those species is the main goal of this project.

Ecopath with Ecosim

A new EwE model is being developed in the area, and first preliminary results have already been published under the DEVOTES EU project framework. The Ecopath model of

the Bay of Biscay (French continental shelf) ecosystem has been built for 1996 (see Figure 1). This new version has 35 functional groups, from phyto- and zoo-plankton up to marine mammals and birds. Most relevant commercial species have been included, as well as two detritus boxes: the common Ecopath detritus box and the one called discards.

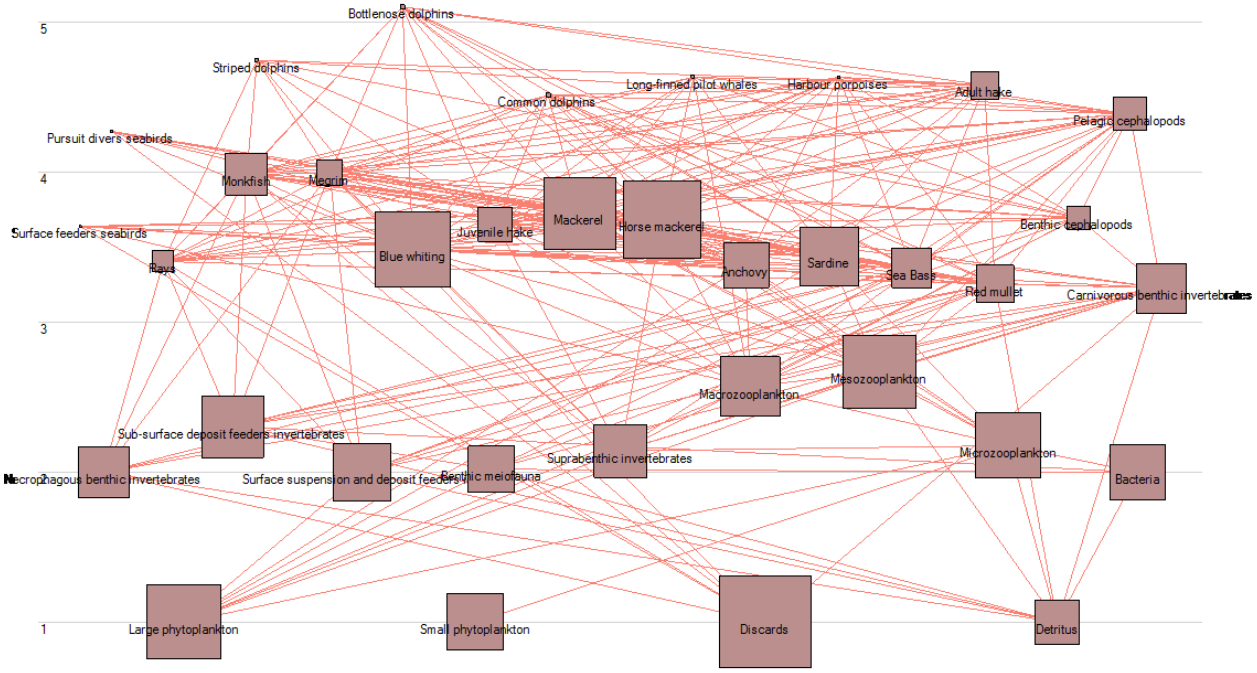

Figure 1. Flow diagram of the new Ecopath model of the Bay of Biscay.

Atlantis

The Atlantis model is being implemented in the south-eastern corner of the Bay of Biscay, for the ecosystem of the Basque Continental Shelf. It is an small area where lot of information is available, from hydrodynamics and habitats, to food-web, fisheries and human activities related to this system.

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3. ToR B: Report on the development of key-runs (standardized model runs updated with recent data, and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (including the Baltic Sea, and others as appropriate)

WGSAM suggests that there is a distinction to be made between accepting a modelling tool as suitable for giving possible advice (or inputs to advice) and accepting the model implementation for a particular set of stocks in a given region. The acceptance of a particular implementations falls within the scope of the periodic acceptance of "key runs" which WGSAM already conducts for the North Sea and Baltic Sea.

A 'key-run' refers to a model parameterization and output that is agreed and accepted as a standard by ICES WGSAM, and thus serves as a quality assured source for scientific input to ICES advice. This process of accepting a key run involves presentation of the 'draft' key run in plenary, followed by nominated experts engaging with the modelling expert(s) to review the specification (inputs), outputs and documentation of a key run. Any required changes are agreed in plenary and documented. When the changes are completed, the nominated experts review them, and when satisfactory, the key run is published in the working group report and output data made available by the ICES website.

Prime purposes of a key run include:

a) Providing consistent outputs relevant for use in assessment working groups and other ICES WGs (e.g. on food-web indicators and trends in biodiversity)

b) Assisting with the development of multi-model ensemble evaluation approaches by providing a "standard" set up to aid understanding of different model frameworks, and a worked example of the results that can potentially emerge.

c) Contributing results for use in multi-model ensemble evaluations of fishing strategies.

d) Demonstrating the utility of a particular model formulation in a controlled environment and thereby building confidence that this formulation is appropriate to use in providing advice.

Key runs are typically run every three years, or alternatively, when a substantive change is made to the model parameters, when sufficient new data becomes available, or when the previous key-run is deemed out of date (WGSAM 2013).

3.1. North Sea EwE

A key run for the North Sea EwE model covering 1991–2013 was produced. This included updates to the input data and some slight modification to the structure of the model. These are described in detail in Annex 6.

The previous North Sea EwE Key Run model (ICES 2012) was updated and calibrated by fitting to time-series data from 1991–2013. The calibration process followed a Pattern Oriented Modelling approach (See Annex 6 for detail), in parameterizing the model to achieve the best possible fit to data while at the same time ensuring credible dynamic behaviour and equilibrium predictions of Fmsy when compared to other model applications for the North Sea (Table 3.1).

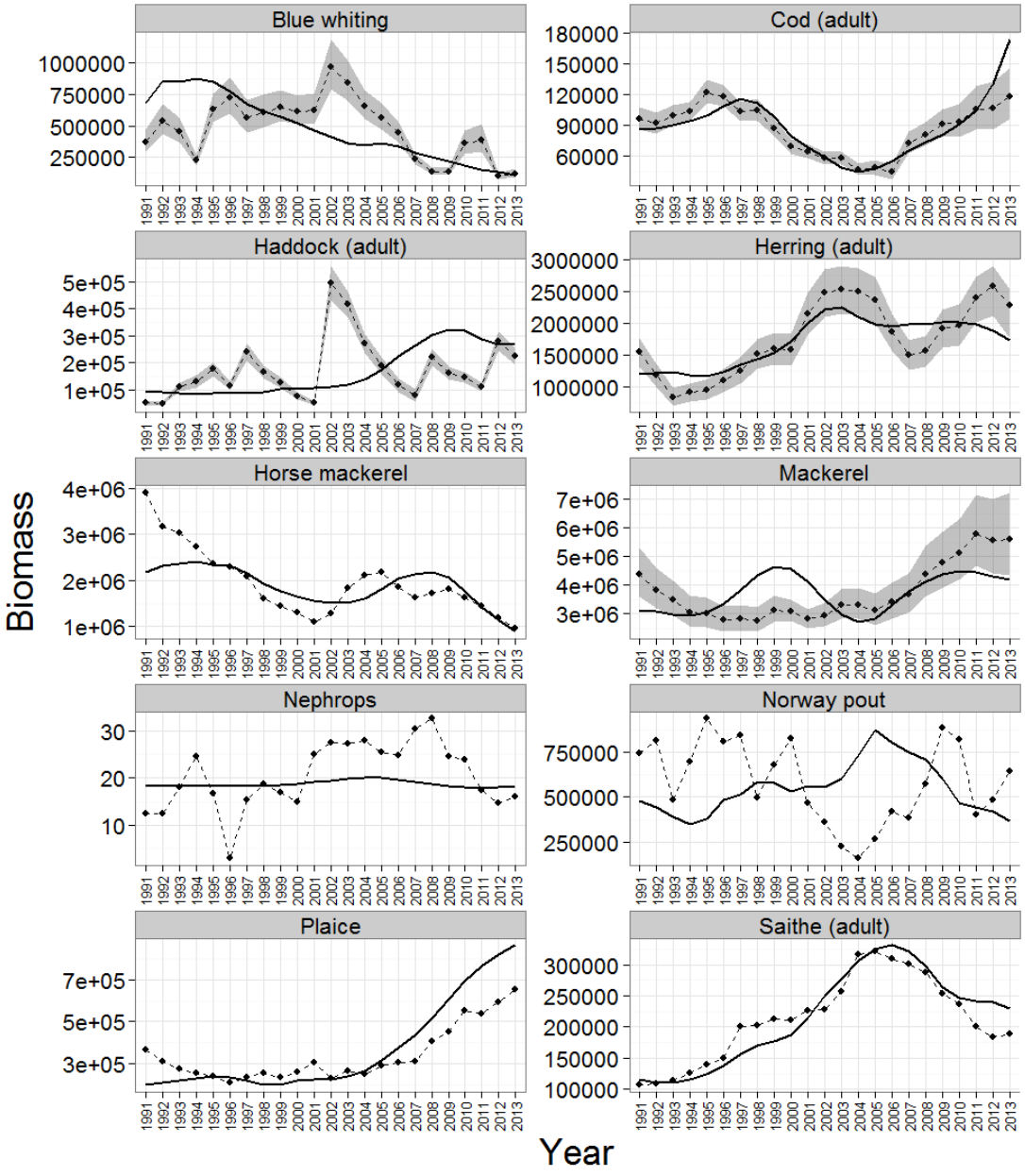
Following protocols established during the first Key Run of the EwE model and analyses from Mackinson 2014), data from all functional groups in the ecosystem are included in the fitting process.

The fit of model predictions to observed biomass data for selected key species of interest are shown in Figures 3.1. A comparison of natural mortality prediction of the EwE key run with the recent SMS key run is shown in Figure 3.2. Changes in selected system and community indicators are shown in Figure 3.3.

Table 3.1. NS-EwE estimated Fmsy ranges compared with two multispecies models, SMS and LeMans, and ICES estimates based on single species models for the North Sea.

FG #	Group/ Species	EwE-NS Key Run 2016 (80% MSY)	Lemans 90% lower and upper CL round ensemble mean Fmsy (Thorpe *et al.* 2015)	SMS Fmsy range (but median SSB may be <Bpa)	ICES WKREF3 single species LowFmsy	ICES WKREF3 single species HighFmsy
6	Spurdog	0.13–0.33				
7	Large piscivorous sharks	0.11–0.4				
8	Small sharks	0.13–0.39				
10	Starry ray + others	0.12–0.16				
11	Thornback & Spotted ray	0.22–0.66	0.14–0.26			
12	Skate + cuckoo ray	0.09–0.32	0.09–0.13			
13	Cod (juvenile 0–2)	0.68–1.28				
14	Cod (adult)	0.38–0.96	0.17–0.27	0.3–0.6	0.13	0.33
15	Whiting (juvenile 0–1)	0.85–1.22				
16	Whiting (adult)	0.41–0.85	0.46–1.03	0.05–0.15	0.144	0.15
17	Haddock (juvenile 0–1)	0.59–1.28				
18	Haddock (adult)	0.31–0.67	0.3–0.72	0.3–0.6	0.25	0.51

FG #	Group/ Species	EwE-NS Key Run 2016 (80% MSY)	Lemans 90% lower and upper CL round ensemble mean Fmsy (Thorpe *et al.* 2015)	SMS Fmsy range (but median SSB may be <Bpa)	ICES WKREF3 single species LowFmsy	ICES WKREF3 single species HighFmsy
19	Saithe (juvenile 0–3)	0.54–1.03				
20	Saithe (adult)	0.3–0.73	0.21–0.45	0.4	0.2	0.42
21	Hake	0.21–0.49			0.24	0.24
22	Blue whiting	0.39–1.08				
23	Norway pout	0.53–1.26	0.52–1.16	0.3–0.6	0.35	0.35
24	Other gadoids (large)	0.4–1.06				
25	Other gadoids (small)	0.45–0.64	0.5–1.08			
26	Monkfish	0.21–0.62	0.15–0.25			
27	Gurnards	0.15–0.22	0.54–1.19			
28	Herring (juvenile 0–1)	0.33–0.72				
29	Herring (adult)	0.22–0.37	0.35–0.73	0.25–0.4	0.24	0.38
30	Sprat	0.3–0.77	0.52–1.04	0.4–0.7	0.32	0.4
31	Mackerel	0.11–0.34	0.32–0.67		0.22	0.22
32	Horse mackerel	0.15–0.39	0.35–0.8		0.044	0.06
33	Sandeels	0.39–1.02	0.67–1.57	0.3–0.6	0.2	0.3
34	Plaice	0.16–0.46	0.15–0.5		0.13	0.27
35	Dab	0.17–0.28	0.57–1.15			
36	Long-rough dab	0.01–0.01	0.54–1.14			
37	Flounder	0.41–1.25				
38	Sole	0.18–0.39	0.44–0.99		0.24	0.41
39	Lemon sole	0.2–0.52	0.33–0.69			
40	Witch	0.23–0.68	0.24–0.49			
41	Turbot	0.16–0.48				
42	Megrim	0.18–0.51			0.26	0.33
43	Halibut	0.04–0.13				
45	Catfish (Wolf-fish)	0.09–0.39				
46	Large demersal fish	0.14–0.45				
47	Small demersal fish	0.43–0.81				
48	Miscellaneous filter feeding pelagic fish	0.73–1.7				
49	Squid & cuttlefish	0.14–0.18				
54	Large crabs	0.05–0.06				
55	Nephrops	0.02–0.05			0.09	0.12
58	Shrimp	1.97–4.27				


Blue whiting
Cod (adult)
Haddock (adult)
Herring (adult)
Horse mackerel
Mackerel
Nephrops
Norway pout
Plaice
Saithe (adult)
Biomass
Year

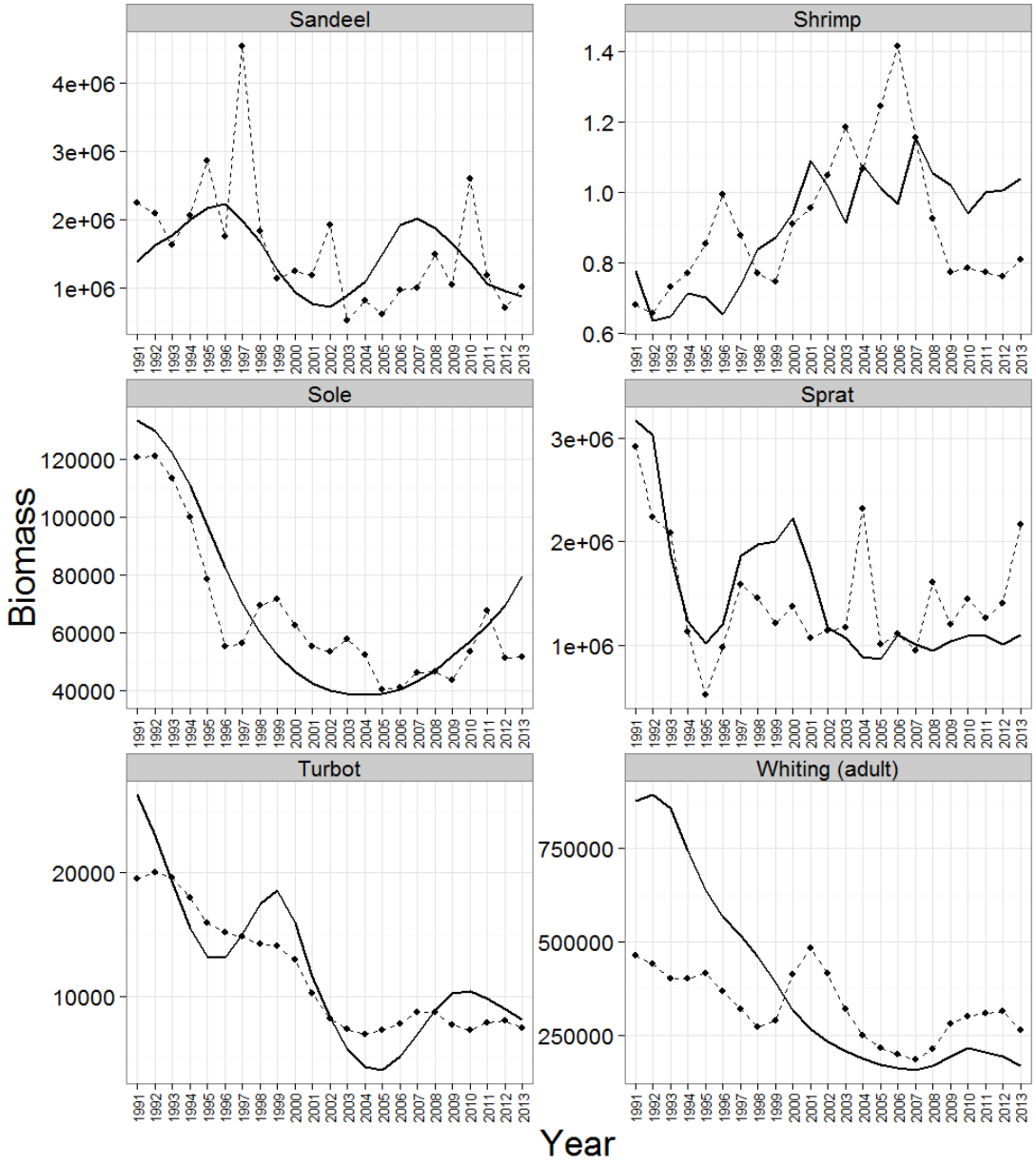


Figure 3.1. Relative biomass plots - observed and model predicted. 'Observed' data are derived from single species stock assessments, 95% confidence interval of the observed data are represented when available (grey area).

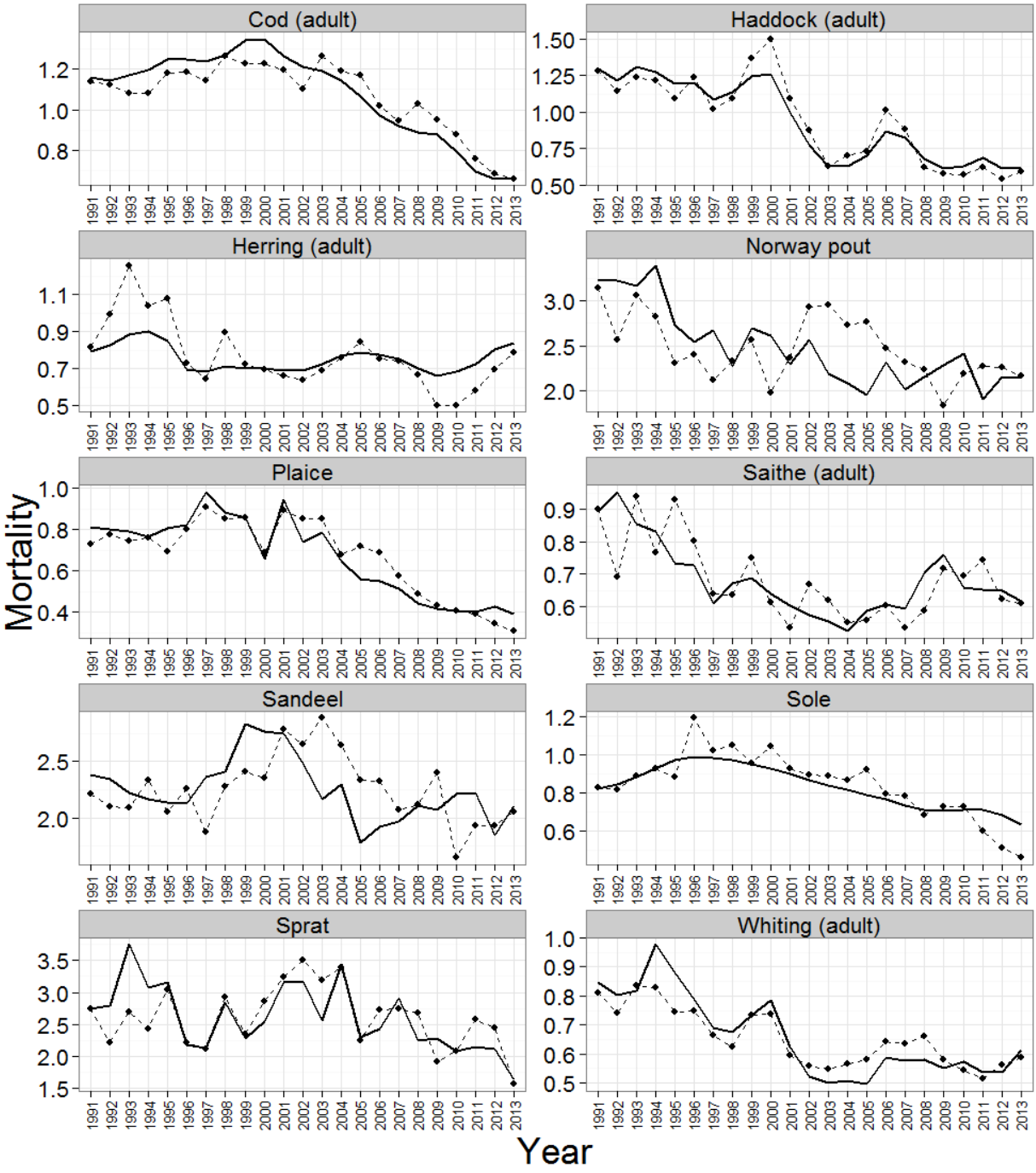
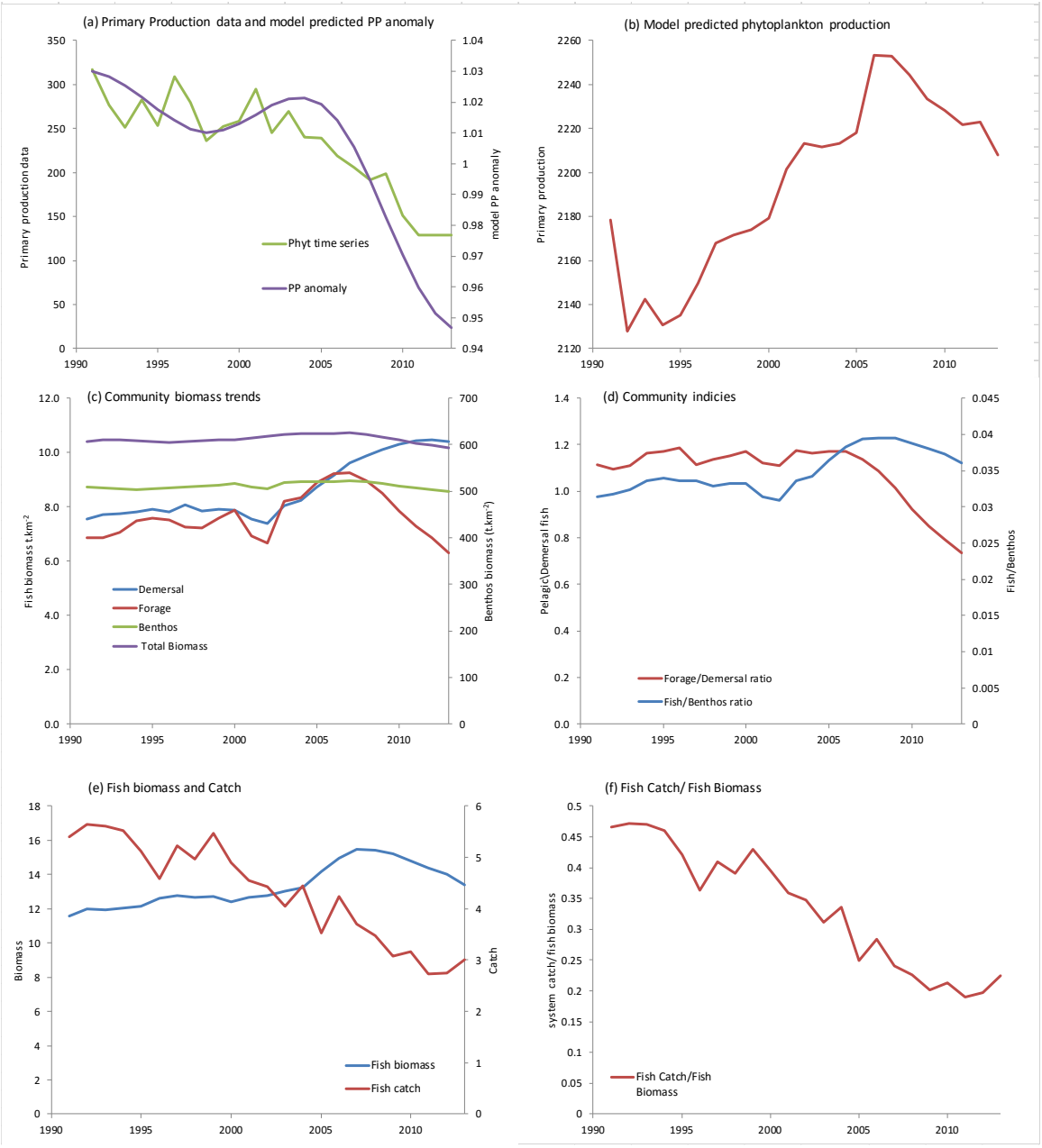


Figure 3.2. EwE Key run Total Mortality (Z) comparison with SMS. Note that Z from SMS is not fitted to in the calibration so serves and a comparison of model predictions.


(a) Primary Production data and model predicted PP anomaly
Primary production data
model PP anomaly
Phyt time series
PP anomaly
(b) Model predicted phytoplankton production
Primary production
(c) Community biomass trends
Fish biomass t.km-2
Benthos biomass (t.km-2)
Demersal
Forage
Benthos
Total Biomass
(d) Community indicies
Pelagic\Demersal fish
Fish/Benthos
Forage/Demersal ratio
Fish/Benthos ratio
(e) Fish biomass and Catch
Biomass
Catch
Fish biomass
Fish catch
(f) Fish Catch/ Fish Biomass
system catch/fish biomass
Fish Catch/Fish Biomass

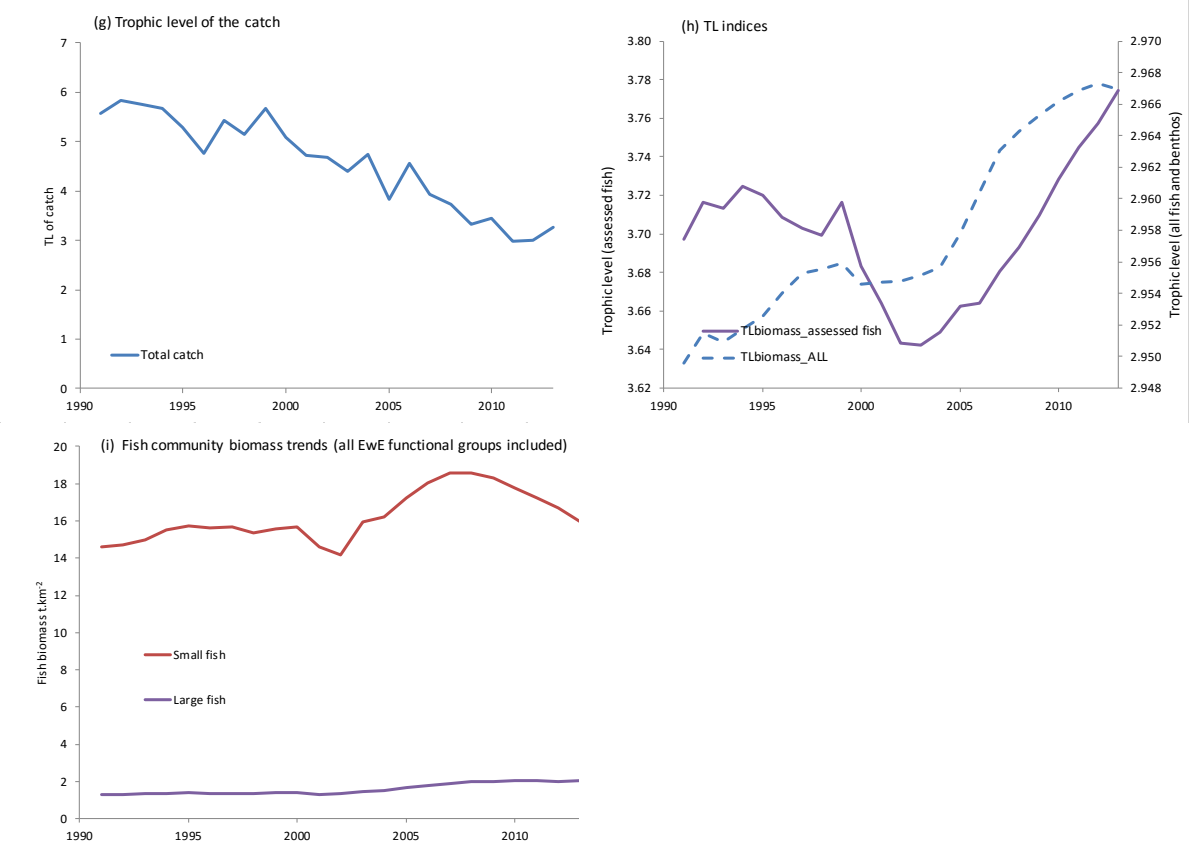


Figure 3.3. Ecosystem indicators derived from the model key run.

During the review of the Key Run by ICES WGSAM several important issues were discussed in relation to confidence in the interpretation of the key run outputs and the application of the model for evaluating research and management questions, and are worth taking note of here.

- The fits to catch data for non-assessed species are quite poor, raising the question whether it's a good idea to fit to the landings of non-assessed species. In many cases there is not an easy answer because it is difficult to disentangle the poor fit from the poor quality of the catch data, particularly in relation to the non-assessed species. We know that the landings data for some species is not representative of what is caught. During the review the decision was set the data weighting for the landings of dab, flounder and gurnard to zero, thereby excluding their influence on the fit. Landings data for some other species are also problematic. For example, spurdog (a zero TAC species since 2010 and restrictive management since 2006), where more recent estimates might be unreliable, and for skates and rays the landings time-series is often problematic due to changes in the species reporting categories. Issues with potentially high discard rates can also mean that the data are unrepresentative of the true catches. In many cases of non-assessed stocks, we find that the model predicts higher catches than reported landings. This issue was also discussed this during the 2011 key run. The conclusion was that the landings data should be used (but

with due caution) because we are dealing with a whole ecosystem model and including constraints at different trophic level is important. Plus while, total amounts might be unrepresentative, the trends still provide useful information. The weighting applied to the times series provides a way to less the effect of any variability in landings data on the fit, and given our awareness of the issues we can identify specific areas of concern related to any application. Furthermore, for the assessed species, where the fits to biomass are best, poor fits to catch data for some species does not necessarily indicate that the biomass fit is good for the wrong reason. For several species (cod being good example) there is strong evidence that environmental drivers may play a larger role in explaining biomass trends.

- Building on the pattern-oriented approach being used to judge the quality of the model fit and its behaviour, it was proposed by the WGSAM expert review group that another useful evaluation could be to compare model estimates of unfished biomass to available estimates of unfished biomass from single species assessments and other mutlispcies models. It would also be of interest to examine the effect of driving the model with catches rather than F. Thus model skill could be tested against not just time-series fits and Fsmy estimates, but also the persistence of stocks when faced with historical catches or in the absence of fishing. This would be a useful test despite concerns over the quality of catch data discussed above. We have taken on board the comments about using catch data instead of F in fitting, as well as other alternatives such as increasing the weighting put on catch, or not including the catch data for non-assessed species in the fitting. This exploration could be quite extensive and unfortunately, given the resources and time, it has not been possible to undertake these additional evaluations of the present Key Run.
- High P/B values in the Ecopath base model were considered to be an issue leading to overly productive stocks, characterised by high Fmsy estimates and rapid rates of recovery. For example, this 'overcompensation' could explain the spike in the model prediction for cod biomass at the end of the run when fishing mortality is much reduced from previous years. In review we looked again at estimates of Z=F+M in 1991 based on the ICES stock assessment data, and could find no justifiable reason to reduce the P/B's in the base Ecopath model. Given that these rates are used to parameterise Ecopath base 'state' and are based on the best available estimates from ICES assessments it's something that cannot be escaped. This type of problem holds for other models, not just EwE; future projections depend on assumption about productivity in terms of growth and recruitment. Furthermore, the high P/B values in the base year might be essential to getting a good fit in the early years, but possibly less so in later years. In relation to this key run, it means that at least we have awareness of the reasons why predictions for some groups might lead to overly or underly optimistic projections when, for instance, fishing is stopped in the model. For many of the species, Z has come down considerably over the last 10 years because of reductions in F and it's comforting that the comparison of key run Z estimates with the recent SMS model key run show close congruency. Furthermore, in relation to future applications, this will not be a cause for concern because our intention is to use the model using a new Management Strategy

Evaluation routine that draws upon 1000's of possible parameterisations of the initial state of the Ecopath model when evaluating the impact of alternative strategies. This way the uncertainty in P/B and all the other Ecopath and Ecosim parameters will be taken account of.

- One suggestion regarding ways to address the issue that a high productivity for some groups (such as cod and haddock) was leading to high Fmsy estimates was to consider allowing non-zero biomass accumulation in a (newly rebalanced) Ecopath model. This has recently been suggested also by Ainsworth and Walters (2015), but it would involve substantial work far beyond the scope of resources presently available. The original decision not to include biomass accumulation in the base Ecopath model was based on the pragmatism of having a model whose starting point is steady state, which provides a strong reference point from which to examine the effect of disruptions in the food web. However, for some species where the biomass dynamcis show clear trends but we do not necessarily a good reason why, there might still be a good rationale for driving their dynamics by including biomass accumulation or Ecopath or through direct forcing in Ecosim. Following the review it was agreed to force the biomass dynamics of seals, hake and gurnards, which have shown large continuous changes in abundance and as top predators we know they will have an important effect on their prey. Where at all possible our intention in establishing a Key Run model was to avoid overcomplicating the model parameterisation – using readily available data and developing a process whereby the Key Run could be updated every few years. For that reason, we feel that the detailed work required to establish a new parameterisation of Ecopath that includes biomass accumulation is better address in a specific research project.

3.2. North Sea SMS model

An error in the input data for the SMS key made at the 2014 WGSAM was spotted in Marts 2015. The error mainly influenced the mortalities for herring and sprat, which were assessed at that time (HAWG, 2015). For herring the HAWG decided to use the 2011 estimates of natural mortalities and to await confirmation of the SMS results from WGSAM.

The updated 2015 key run for the North Sea SMS was reviewed by a subgroup of WGSAM members. The SMS code and associated diagnostic R scripts was installed on computers of the subgroup members as "knowledge transfer" but also to allow a closer look at the code and to be able to reproduce the results from the review process during the WGSAM meeting. The review of the results from then 2015 key run was mainly a comparison of the stock dynamic and natural mortalities from the two key runs. Among dynamically modelled species, the key runs biomass outputs are remarkably similar for cod, haddock, herring, and saithe, between the two runs. Norway pout and sprat have differences between the key runs; sprat because the whole catch data input have been revised for alignment to data used by HAWG. Norway pout differences arise from the inclusion of hake as a predator on Norway pout in the model since 2011—this is a structural change. Sprat differences arise from changes to virtually all input data due to a new benchmark assessment. Changes in the stock sizes "Other predators" with fixed popula-

tion numbers were presented and commented. *Raja radiata* data have been corrected since the 2011 key-run. Abundance of harbor porpoise is kept constant over as there is no data to confirm a significant change in abundance. Grey seals are increasing over time. Grey gurnards are of particular interest because they are driving mortality on cod and whiting, and gurnard biomass is increasing, even though is seems a plateau has been reached.

The review sub-group concluded that the 2015 SMS key run results looks reasonable and are performing consistently with the previously accepted 2011 key run. Based on this review and a quick review of the provided code and associated visualization scripts, the subgroups recommends that WGSAM accept the 2015 SMS key run and provide it for use in other ICES working groups. This conclusion was confirmed by the full WGSAM.

The reviewers also discussed methods for preventing the 2014 data entry error and other potential checks that could be incorporated into the SMS key run process moving forward. The simplest suggestion is to use an EOF statement to ensure that the expected number of rows have been read in from the data file, and this type of check was implemented in the SMS code during the meeting (and no errors were found). It was noted that this would prevent an error of omission but would not catch an entry that was the incorrect value. Additional checks on more specific data input sections were also discussed and could be implemented in the future. Other data and formatting checks can be built in with more precision; also R packages in Hmisc with summary statistics could do a data input sanity check. Sigrid Lehuta contributed an r script to read in the SMS input files and plot inputs to provide a visual check to ensure that inputs were in the correct order and at the correct scale, etc., for each species. These tools can be used in future key runs to catch any errors at an early stage and could also be used by reviewers to improve the key run process for SMS and other similar models.

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ICES. 2014. Interim Report of the Working Group on Multispecies Assessment Methods (WGSAM), 20–24 October 2014, London, UK. ICES CM 2014/SSGSUE:11. 104 pp.

4. ToR C: Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs)

4.1. Some leads toward improved confidence and transparency in WGSAM models

S. Lehuta presented methods to help improve transparency and confidence in models used in WGSAM. Given that Key Runs results are used to inform single species assessment models and thus advice, it is necessary to have assurance quality on the runs. It requires proper documentation and appropriate and transparent handling of uncertainty. The group already developed a base for model documentation ("summary sheets"), which could be completed with regards to (i) rational for model choice and legitimacy, confidence in data used (pedigree matrices), (ii) key assumptions, alternative hypotheses

and model sensitivity to these, (iii) model skill assessment. With regards to (i) the author presented excel based matrices, increasingly used in European groups and projects, describing each processes in the model and allowing easy comparisons between different models. As far as uncertainty is concerned, the group already uses routines to estimate uncertainty in estimates. Model fit to independent data (data not used in estimation phase), frequently referred to as "model validation", can seldom be investigated for the models used in WGSAM. Methods should consequently be investigated including jackknife re-sampling, simulation-estimation and perturbation analyses. In cases when validation is possible, model skill assessment tools (iii) were presented (Joliff *et al.* 2009, Sterman, 1984, Lehuta *et al.* 2013) based on various summary statistics and graphs. Sensitivity analysis methods (ii) are a way to explore model behavior and could be used to identify most influent parameters and processes, which require further work, assess sensitivity to alternative hypotheses and evidence interactions. Examples of possible uses and methods of sensitivity analyses were presented (Lehuta *et al.* 2013, Lehuta pers.comm.).

4.2. Multispecies model performance testing, and multimodel inference: examples from Georges Bank

Sarah Gaichas presented "Multispecies stock assessment for Georges Bank: model development, performance testing, and multi-model inference." The work is by Gaichas, M. Fogarty, R. Gamble, S. Lucey, L. Smith, C. Perretti (NEFSC) and G. Fay (SMAST) and is a preliminary simulation analysis testing the performance of three fairly simple multispecies models and an ensemble of models using a multispecies operating model. The operating model (Hydra) is implemented in ADMB and simulates ten species with length structured population dynamics, predation, and fishery selectivity with fishing mortality coming from three effort-driven multispecies fleets. Multiple forms for growth and recruitment are implemented in the operating model so that each species may have different combinations within the model structure (e.g. von Bertalanffy growth with Ricker recruitment, exponential growth with Beverton Holt recruitment) and environmental covariates for each function can also be included. There is no feedback between prey consumption and predator growth in Hydra. The much simpler estimation models were multispecies production and delay difference models. These included Kraken, a multispecies production model using a genetic algorithm for parameter estimation (described in further detail below), and two models (one production, one delay-difference) implemented in SAS using full information maximum likelihood for parameter estimation. Kraken can estimate survey catchability and observation error while the SAS models are process error only models that do not estimate survey catchability. All estimation models assumed catch was known without error.

Within a simulation framework developed in R, Hydra first generated one hundred simulated survey biomass and catch time-series with stochastic recruitment under four different error scenarios: no error or "perfect knowledge", survey observation error only, survey bias only, and both survey observation error and bias. Each multispecies assessment model was then fit to the simulated data under each error scenario, and assessment model estimates of biomass and catch trends were compared with "true" operating model values for each time-series under each error scenario using a variety of skill assessment metrics, including the modelling efficiency, MEF (Stow *et al.* 2009). MEF is a particularly

useful skill assessment metric as it establishes a lower bound for acceptable performance because MEF>0 indicates that a model adds value over simply averaging observations, while other skill metrics such as RMSE are simply relative measures of fit. Results from all three estimation models were then combined into an ensemble using a simple average of biomass estimates and this ensemble mean was compared with Hydra-simulated true data.

Each model was evaluated for its skill in recovering the true simulated biomass time-series under each scenario. Both the SAS production and delay difference models performed exceedingly well for the perfect knowledge scenario with all species MEF>0 for all runs. However, performance of the SAS models degraded with any introduction of error, as would be expected for a process error only model confronted with observation error and bias in input data. Conversely, Kraken's performance was poor for certain species even in the perfect knowledge scenario, but median MEF was >0 for dogfish, haddock and yellowtail flounder. Interestingly, in the bias and observation error scenario, median MEF remained >0 for these species and increased above 0 for cod as well. Kraken estimates survey catchability and accounts for observation error in input data so performance was more consistent across error scenarios. Some species such as silver hake apparently pose a difficult estimation problem across all models.

The simple model ensemble performed better across error scenarios than any individual model for nearly all modelled species, with silver hake being the exception. Even in the perfect knowledge scenario, including the poorer performing model alongside the better performing models did not degrade ensemble performance aside from silver hake MEF<0. In the most realistic data scenario (bias and observation error) the ensemble MEFs were >0 for 5 of the ten species and increased for all other species relative to individual models aside from silver hake (Figure 4.1).

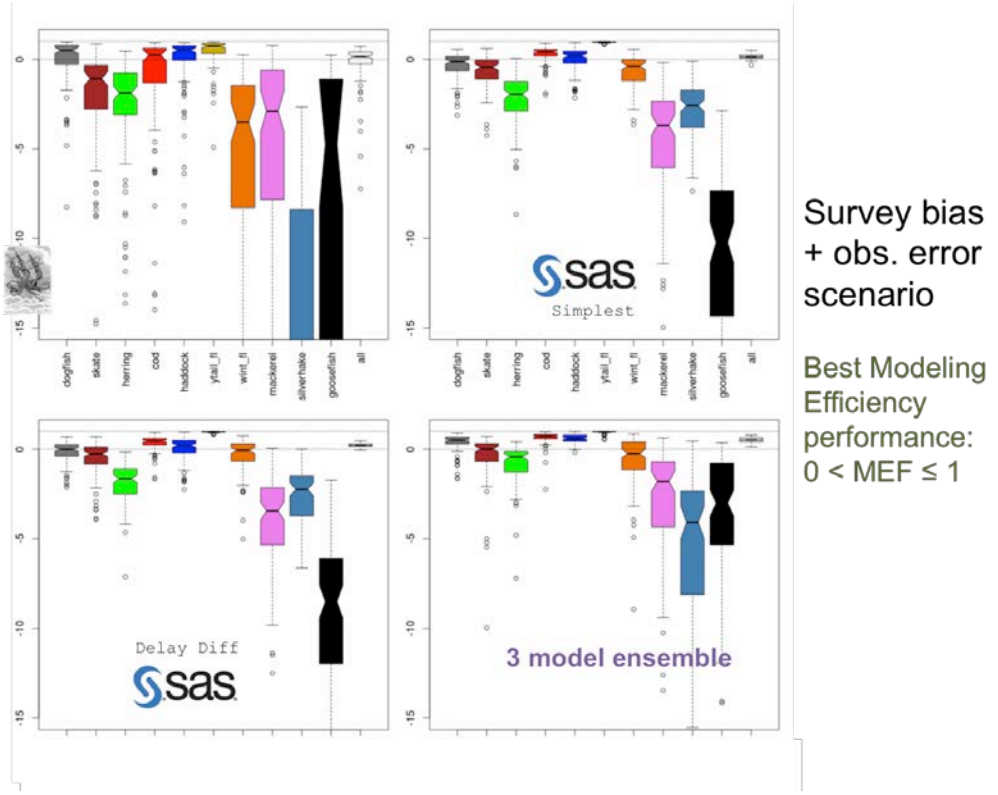

Figure 4.1. MEF distributions for fits to biomass by species over 100 model simulations for the most realistic data scenario with both survey observation error and bias.

Next steps in this work include refining the estimation models based on these results to improve fits for species with high recruitment variability such as herring and mackerel, and to investigate why silver hake dynamics are so difficult to fit. Fits to aggregate species groups will also be evaluated, as well as other methods to improve ensemble performance. Estimates from the multispecies assessment models will also examined for retrospective bias using this framework. This process both improves the multispecies models and informs managers of their strengths and weaknesses for operational use.

Kiersten Curti presented a model inter-comparison, which is an example of one of the steps in validating and verifying multispecies models suggested by Sigrid Lehuta (see section 4.1). Kiersten and Robert Gamble modelled 9 fish species from Georges Bank (a shallow region off the coast of Massachusetts in the Northeast U.S. Continental Shelf Large Marine Ecosystem) with 27 predator prey interactions in an age structured multispecies statistical catch at age model (SCAA) and a multispecies production model (Kraken) both fit to the same survey indices but using different inputs and assumptions. The purpose was to see whether the view of the ecosystem is different between these different model structures by comparing trends in the model outputs of biomass, predation, and consumption. The SCAA model inputs included age structured commercial catch, survey catch, and predator food habits data. For each modelled species, SCAA estimates 1st year abundance, annual recruitments, annual F, fishery selectivity, survey selectivity and catchability, and food selection parameters, including species preferences. Size preference proved difficult to estimate within the model so these parameters were estimated outside

the model with predator-prey length data instead. In contrast, Kraken takes aggregate survey biomass and catch time-series as inputs (and currently assumes that catch is known without error) and estimates intrinsic growth rate and Type 1 interaction parameters. In this simple formulation, all interactions between species were parameterized as predation with no feedback from prey on their predators. The same interaction parameter was also estimated within species as a density dependent parameter. Kraken uses a genetic algorithm for parameter estimation with MEF as a fitness criterion.

Individual model results were presented and then comparisons between models were made. SCAA predation mortality varies substantially over time and age. Mackerel, herring, and silver hake are subject to predation mortality at all ages, while others outgrow predation. Mackerel, silver hake, and herring also had higher predation mortality than fishing mortality, while other modelled species had higher fishing mortality than predation mortality. Goosefish (monkfish) was a dominant predator in the first model run, and herring was consumed by the biggest diversity of species. Comparisons of total predator consumption (including the other food category) to biomass showed low consumption relative to biomass for elasmobranchs, more similar levels of consumption and biomass for cod and pollock, and higher consumption than biomass for goosefish, white hake, and silver hake. A sensitivity run with reduced goosefish consumption showed higher influence of cod and other predators than in the base run. Comparing the results of SCAA with Kraken showed very similar estimates of total biomass for cod, goosefish, mackerel, pollock, and herring (Figure 4.2). Elasmobranch biomass was much lower in Kraken relative to SCAA. Model fits diverged most widely for white and silver hakes (and we noted the connection with the previous presentation that silver hake was most difficult to fit in simulations). Predator consumption was different between models, with spiny dogfish a more important predator in Kraken than in SCAA. Mackerel and herring in Kraken have greater losses due to species interactions than to fishing, similar to SCAA.

Overall, this work demonstrates that multiple modelling approaches provide similar estimates of absolute biomass, though the underlying dynamics between models are different. For the principal prey species, losses due to predation generally exceed fishery landings. The differences between models demonstrate need for multiple approaches. Planned future work includes exploration of SCAA and Kraken model performance using simulated data, and separate evaluation of cannibalism and density dependence in a more complex production model. This work provides additional tools for incorporating predation and multispecies considerations into fisheries management.

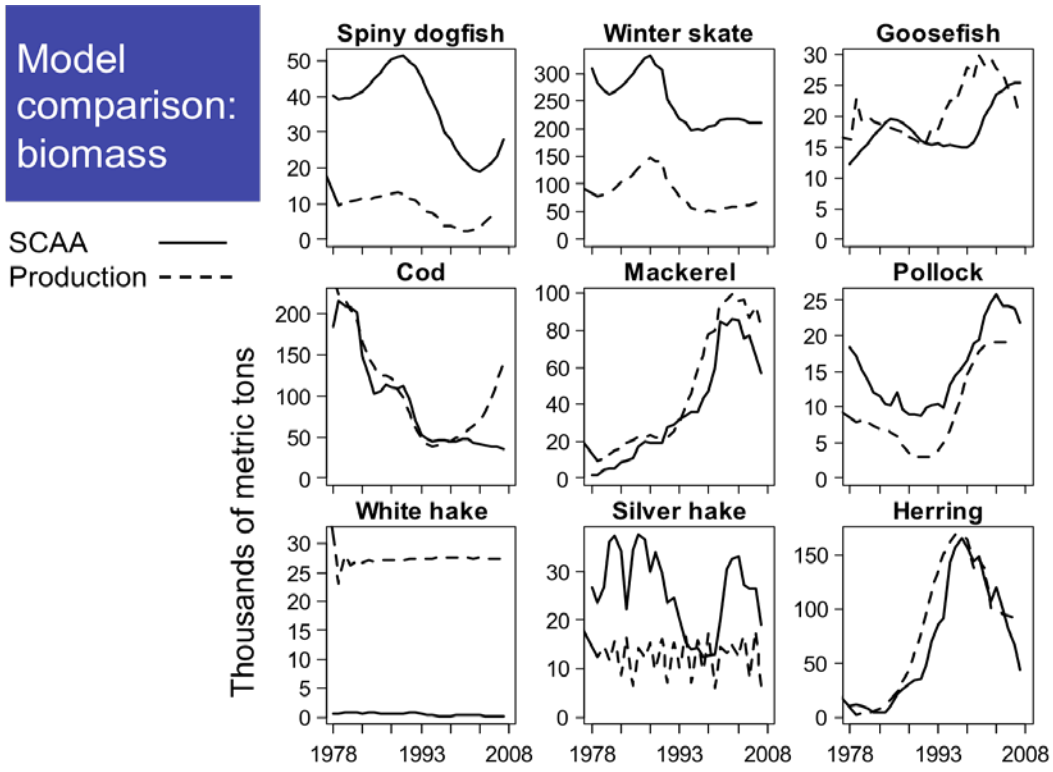

Figure 4.2. Comparison of biomass estimated for 9 Georges Bank species from a multispecies statistical catch at age (SCAA) model and a multispecies production model (Kraken).

4.3. Multi-model approaches

There are many sources of uncertainty. One of the most helpful ways of characterising these sources is shown in Table 4.1. Uncertainty due to lack of knowledge about the current state of the system at any time (measurement error) is an additional source not shown here.

Table 4.1. Types of uncertainty and their impact on the two broad classes of modelling, tactical (operational) modelling dealing with near term forecasting, and strategic (often equilibrium) long term modelling.

UNCERTAINTY CLASS	Tactical/Operational Model "Weather forecast"	Strategic Model "Climate"
Initial Conditions	Significant **Amenable to statistical analysis**	Generally Low **Unless system has hysteresis**
Scenario	Often low	Significant **Use storylines or scenario ensemble**
Model Parameter	Significant **Amenable to Monte Carlo methods**	Significant **Amenable to Monte Carlo methods**
Model Structure	Significant **Difficult – need structural analysis/ alternative model approaches**	Significant **Difficult – need structural analysis/alternative model approaches**

Of these sources of uncertainty, three types are amenable to analysis by various methods, but the fourth, model structural uncertainty is less tractable. Without alternative model structures being interrogated in a compare and contrast manner, it is hard even to make a qualitative estimate of this uncertainty.

We also discussed our perspective on how stakeholders tend to respond when successively more complex outputs are presented to them. A single deterministic output is easy to understand, and philosophically coherent, but wrong. When we presented three storylines to illustrate uncertainty, the stakeholders would home in on the middle one, wrongly ignoring the other two. When four storylines were presented to get round this problem, the stakeholders spent so much intellectual capital calculating where the "middle" of the scenarios was that they would ignore the others completely. Finally, when a probability density histogram was presented, stakeholders tended to do one of two things. Either they would decide that everything was too complex and therefore opt to do nothing ("Decision paralysis") or else they would be fooled by the apparent mathematical rigour of the output and conclude wrongly that nothing outside of the probability distribution could possibly happen ("False Confidence").

There is frequently an additional hurdle to overcome, in that the probabilities may not be framed in terms of quantities that are meaningful for stakeholders. For example, potential annual rainfall may be directly relevant to the decision as to whether a water company needs to build a new reservoir (Figure 4.3), but it may be difficult for the stakeholder to immediately make a connection between the output and any decision-thresholds or risk tolerance that they might have.

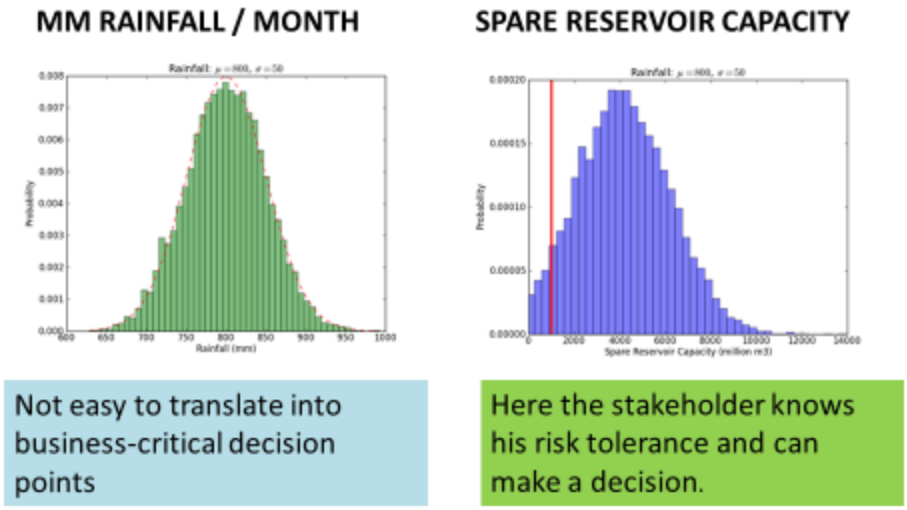

Figure 4.3. Probability distributions of (left) rainfall, and (right) estimated spare reservoir capacity as determined from climate model output.

On the other hand, if the same information could be post-processed into a projection of spare reservoir capacity, a quantity the stakeholder would have a defined risk tolerance threshold for, it would be relatively easy for them to frame a decision based upon the presented information.

However, if the decision is to be a good one, the presented probability distributions need to reflect the true uncertainty, which includes structural uncertainty due to models. Therefore a decision should ideally be based upon more than one model. Consider the set up in Figure 4.4.

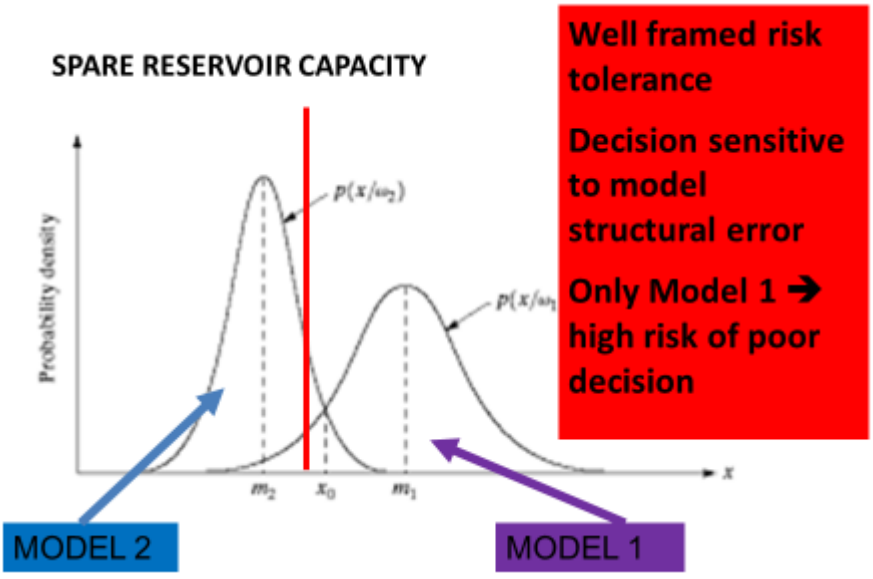

Figure 4.4. Schematic showing impact of model structural uncertainty (model 1 vs model 2) on probability of business critical outcomes.

If there is not a clear reason to prefer one model over the other to answer the particular issue at stake, a decision made on the basis of say model 1 alone is quite likely to prove a poor one. Any probabilistic assessment needs to take account of all the sources of uncertainty including structural uncertainty to be well framed, so we recommend that multi-model approaches should be used where possible. There are two broad approaches that could be utilised, off-line model inter-comparison, and online multi-model ensembles. In the first approach, models separately address the same problems or case studies, similar outputs are analysed, compared, and contrasted, with the aim being to gain mechanistic understanding of system and develop better models. In the online approach, models run together in same ensemble system, and ensemble products seamlessly integrate all the model outputs.

An example of this approach from climate science was presented. In this study (Gregory *et al.*, 2005), the thermohaline circulation responses of 11 climate models were compared, through a common experimental design with common analysis methods. Agreeing the design of experiments and analysis in advance took more effort than doing the actual experiments, and the design had to take account of the lowest common denominator amongst the models so those with more advanced features did not use them. This study yields a couple of insights into behaviour common across the models. There was a robust signal for transient weakening, no sign of the hitherto feared circulation collapse, and in all cases heat fluxes were more important than freshwater. Whilst the paper took 4 years from the initial meeting it was definitely worth it in the end!

Online approaches are common in weather forecasting, where the benefits have been apparent for a long time (Krishnamurti *et al.*, 2000) and we could learn from the methodology used by weather forecast centres such as the UK Met Office, ECWMF, and NOAA.

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5. ToR D: Develop and compare foodweb and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO)

No contributions were made to this ToR in 2015.

6. ToR E: Report on progress on including new stomach samples in the ICES area in multispecies models

In ToR A we reported initial results from a new LeMans model of the Celtic Sea which has recently been developed. This is an 18 stock ensemble multispecies model, in which predation interactions are represented by one of five possible diet matrices. These diet matrices were compiled with reference to the recently updated DAPSTOM database including new stomach samples from the Celtic Sea.

The collaboration with the Working Group on Biological Parameters (WGBIOP) on data includes a discussion of stomach data, and is described in Section 10.2.

7. ToR F: Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points

7.1. Multi-species trade-offs related to California Current sardine

Isaac Kaplan presented Atlantis end-to-end modelling results for the California Current, focused on understanding the food web impacts of the recent decline in the sardine population. This work illustrates multi-species trade-offs, although explicit estimation of fishery reference points is not the main focus. The project is part of the Ocean Modelling Forum (http://oceanmodellingforum.org/), which is utilizing Atlantis, Ecosim, a simple multispecies MICE model, and empirical relationships to predict impacts on predators of sardine, such as pelicans, California sea lions, dogfish, and humpback whales. A major portion of this project has involved bringing expert advice and new literature and parameter estimates into the suite of models. Like previous food web modelling related to this question (Smith *et al.* 2011; Kaplan *et al.* 2013), modelling experiments test the direct and indirect effects of a range of sardine fishing mortality rates; new work involves the use of time varying sardine and anchovy recruitment, improved taxonomic resolution, and an emphasis on spatial effects since both fishing and predators are concentrated in roughly the same areas of the coast. Preliminary results indicate that sardine depletion may lead to slight increases in prey of sardine including krill (euphausiids), but moderate decreases in some predators of sardine such as pelagic shark, pelagic-feeding seabirds, and dogfish sharks. Biomass of some groundfish stocks increased when krill increased, but only if we assumed groundfish were highly mobile predators able to easily find and move to krill concentrations. In addition to these coastal scale impacts, for select locations near sardine fishing ports, preliminary results suggest additional declines in some sardine predators, including tunas, mammals, and birds.

7.2. Nash equilibira as potential solutions to multispecies MSY-conflicts

Introduction

Single species MSY (SMSY) reference points are often in conflict for species that are interacting in the same ecosystem. From the perspective of maximizing the yield of one stock, fishing on species that are predators or competitors should be as high as possible, whereas fishing on prey species should be as low as possible (Christensen and Walters, 2004). There have been some suggestions in the literature to resolve these conflicts but they all have had their disadvantages (e.g. May *et al.* 1978, Beddington & Cooke 1982, Gislason 1999). Also, few of them have been used in management.

MSY reference points are products of the resilience, the ability of the stock to compensate for increased fishing mortality. They actually depend on the resilience of the ecosystem. If fishing mortality on a stock increases, the predatory mortality decreases on its prey, which will be more abundant and provide a greater growth potential for the predator population. This resilience is not included in SMSY analyses, and therefore multispecies MSYs (MMSY) often provide higher FMSY than SMSYs.

The work that has been conducted has aimed at an MMSY but to preserve an equal interest to achieve MSY across stocks. For this we have looked at game theory and the Nash Equilibrium (NE; Nash 1951). The NE is defined as the strategy for each player that maximizes the payoff when the other players are playing fixed strategies. When we apply it to to solve MMSY, each stock is regarded as a player and hence preserves an equal interest of fishing each stock at MSY.

Methods

A multispecies model interactive stochastic operative model (MSI-SOM) was developed for the Baltic Sea main basin to be operative in the analyses. It included three species, two prey (herring and sprat) and one predator (cod). Each stock was modelled with numbers-at-age and weight-at-age as state variables. For functions defined the change in the state variables from year-to-year: a recruitment function, a mortality function, a weight of recruits function and a body growth function. The ecological interactions were manifested by including the biomass of the prey in the predator's growth function, and the biomass of the predator in the preys' mortality functions. The functions were fitted to input data to ICES working groups assessments, output from the assessments, and assessments from the SMS model (ICES 2013).

We tried two different conditions for NE, one based on keeping the biomasses of the other species constant (BNE) and one on keeping the fishing mortality constant (FNE). The BNE analysis basically involved running the MSI-SOM keeping the SSB of the two other species constant and maximising the yield for the third. By stepping through a range of fixed SSB for the two controlled species, we could calculate a FMSY response of the third. When we had extracted the BMSYs of each species, we could solve when these were the results of the other two species being at BMSY. The procedure was the same for FNE, whereas here the Fs of the other two species were held constant. It means that in the latter case, biomasses of the other two species were changing when F was varied for the focal species.

Results and discussion

The NE equilibria were find both as BNE and FNE. The BNE solution was facilitated by the fact that the two prey species were substitutable in the predator's growth function, although a conversion weight had to be applied. The cod BMSY line intersected with clupeid BMSY line (as herring equivalents), and the intersection defines the mutual MSY response between predator and prey. In other words, this defines the BNE (Figure 7.1).

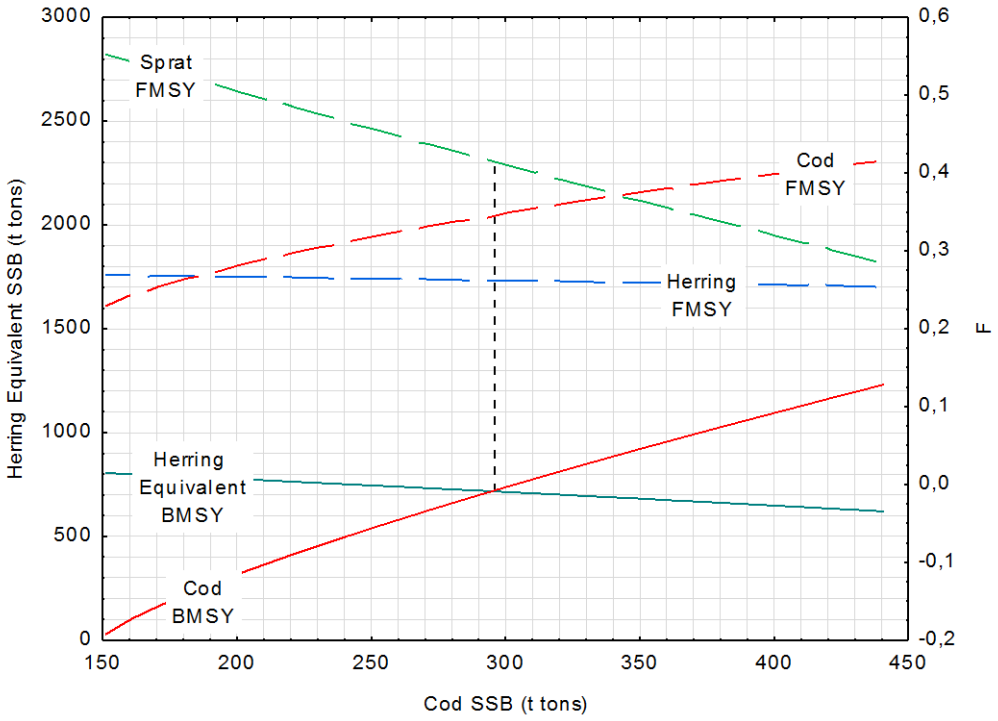


Figure 7.1. B_{MSY}-isolegs for cod (black line) and clupeids (red line) in terms of herring SSB equivalents (sprat SSB weighed by its impact on cod in relation to herring) with corresponding FMSYs. The F-values for sprat (dashed red line) and herring (dotted red line) given the cod SSBs, and the F-values for cod given the herring equivalent SSBs (dotted black line) can be read on the right y-axis. (Depicted from Norrström *et al.* unpubl.).

The FNE was defined by analysing the FMSY landscapes. These were contour plots of the FMSY of one species as a function of the Fs of the other two species. The FNE was depicted by the intersection of these landscapes in three dimensions (Figure 7.2). Also in this case, there was no proof that the NE should exist. However, the low variation herring FMSY restricted the range and facilitated a single point FNE. The reason why the herring was so insensitive to the other species' Fs, is probably that it is only susceptible to predation at the youngest age classes and grow out of predation with older age. The ageing act as a refuge on the stock, which then can form a rather stable FMSY.

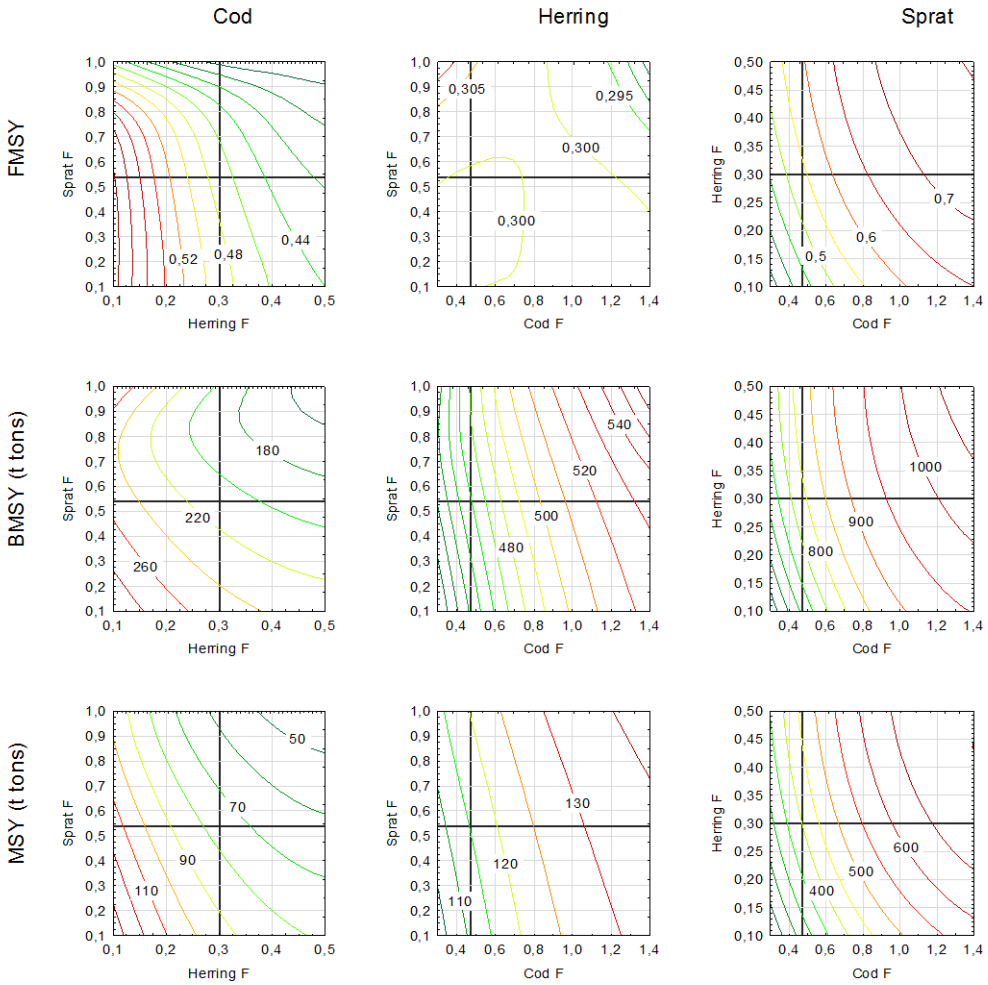


Figure. 7.2. Contours of F_{MSY} (upper row), B_{MSY} (middle row) and MSY (lower row) planes for cod (left column), herring (middle column) and sprat (right column) plotted as functions of F of the other two species. Results are from deterministic simulations to solve FNE (F-based Nash Equilibrium), i.e. the Fs at which all three species are fished at MSY. The FNEs are indicated with lines in the upper row and are for cod: 0.47, herring: 0.30, sprat: 0.54, and can be confirmed by reading the dependent FMSY (the contour lines) in the intersection (independent Fs). The contour planes are fitted to data with least squares.

The NE approach is a stock neutral method to solve MS-MSYs. The likelihood of finding point solutions in ecosystems may decrease with the number of fished species, but this remains to be investigated. An NE analysis can still heavily restrict the multidimensional FMSY space and be very useful in management. The application to the Baltic Sea is not yet ready for implementation. In this system, as in other attempts to apply MS-MSYs, the MS-FMSYs are substantially larger than the SS-FMSYs. A more comprehensive study of the resilience factors must be done.

7.3. Consequences of MSY range estimates in an idealised 4-fleet North Sea Fishery – Robert Thorpe (CEFAS, UK)

Results of an ensemble-based numerical simulation of the consequences of MSY/PGY style ranges on the operation of an idealised 4 fleet North Sea fishery were presented. The purpose of the simulation was to answer the question "what is the probability that range estimates for the North Sea will be multispecies precautionary, given uncertainties in model parameters, management targets, and possible fleet scenarios?"

The building blocks of the study were:

a) An ensemble model system,
b) A definition of multispecies precautionary
c) A definition of FMSY targets to manage towards
d) A definition of the four fleets
e) A description of the risk-reward space and thoughts on how to evaluate it.

The overall methodology of the approach is summarised schematically in Figure 7.3

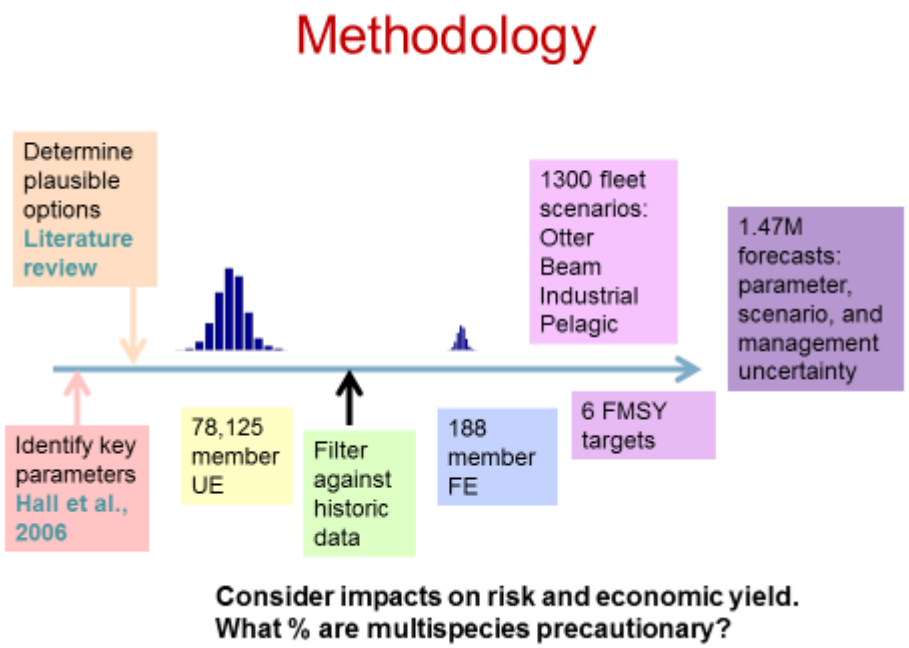


Figure 7.3. Schematic of the study approach in which an ensemble model system is used to evaluate MSY ranges given uncertainties in fleet management, FMSY targets, and model parameters.

The ensemble model system used is documented in Thorpe *et al.*, 2015. It is a size-structured fish community model with 21 stocks represented in up to 32 length classes of 5cm each. The ensemble members are drawn from a population of 78 125 models which both preserve all stocks and reproduce estimates of biomass from ICES for 10 assessed stocks in the period 1990–2010 to within a factor of two. Within this population, seven parameters were varied, recruitment fertility and carrying capacity, life history traits,

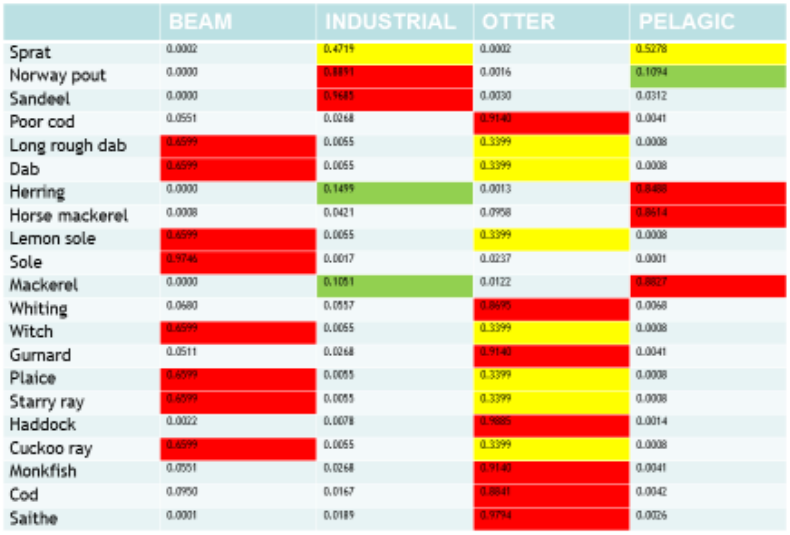
relative size-preferences for predation, growth efficiency, permitted diet interactions, and non-predation natural mortality. Possible values were determined by expert judgement with reference to the literature. 188 models were found to persist all stocks and adequately simulate overall biomass, and these were used as the ensemble of "adequate models".

The desirability or otherwise of the outcomes was assessed by looking at their risk-reward properties. Risk was measured in terms of the average number of recruit-impaired stocks in the ensemble, whilst reward was measured in terms of economic value of the catch. If the range concept is valid, then the risk/reward outcomes should be similar across the entirety of the range, or at least all the range-consistent options would be safe (precautionary). Five possible types of outcome were identified, of which the first three would be considered bad and the latter two good or acceptable.

- Domination of high risk options
- Large spreads in risk/reward space
- Clustering around unacceptable risk/reward
- Domination of low risk outcomes
- Small spreads around acceptable risk/reward

Fleet uncertainty was addressed using a combination of 1300 basic patterns involving differential effort from four fleets, beam, industrial, pelagic, and otter. Some scenarios were dominated by one, two, or three fleets, others were more balanced. The fishing mortality was scaled up in accordance with the underlying pattern until such a point that one of the stocks became a choke stock when compared with the management FMSY target. This process was repeated for each of the 6 FMSY management targets; multispecies FMSY 5%, multispecies FMSY central (ensemble mean), multispecies FMSY 95%, single species FMSY (lower), single species FMSY (central) and single species FMSY (upper).

Partial fishing mortalities from the fleets were calculated from STECF data for the period 2003–13, and are shown in Figure 7.4. In general the industrial and pelagic fleets catch small forage fish and pelagics, whilst the other stocks are caught in the beam and otter fisheries. The beam fleet focusses on flatfish and bottom dwellers, whilst the otter fleet catches mainly larger gadoids.



	BEAM	INDUSTRIAL	OTTER	PELAGIC
Sprat	0.0002	0.4719	0.0002	0.5278
Norway pout	0.0000	0.8891	0.0016	0.1094
Sandeel	0.0000	0.9685	0.0030	0.0312
Poor cod	0.0551	0.0268	0.9140	0.0041
Long rough dab	0.6599	0.0055	0.3399	0.0008
Dab	0.6599	0.0055	0.3399	0.0008
Herring	0.0000	0.1499	0.0013	0.8488
Horse mackerel	0.0008	0.0421	0.0958	0.8614
Lemon sole	0.6599	0.0055	0.3399	0.0008
Sole	0.9746	0.0017	0.0237	0.0001
Mackerel	0.0000	0.1051	0.0122	0.8827
Whiting	0.0680	0.0557	0.8695	0.0068
Witch	0.6599	0.0055	0.3399	0.0008
Gurnard	0.0511	0.0268	0.9140	0.0041
Plaice	0.6599	0.0055	0.3399	0.0008
Starry ray	0.6599	0.0055	0.3399	0.0008
Haddock	0.0022	0.0078	0.9885	0.0014
Cuckoo ray	0.6599	0.0055	0.3399	0.0008
Monkfish	0.0551	0.0268	0.9140	0.0041
Cod	0.0950	0.0167	0.8841	0.0042
Saithe	0.0001	0.0189	0.9794	0.0026

Figure 7.4. Percentage of mortality due to each fleet when they all fish with the same intensity. Major sources of mortality (>60%) are red, moderate sources (>30%) are yellow, and modest sources (>10%) are green.

Catches were converted into economic value using mean first prices fetched at UK markets (Figure 7.5).

STOCK	£ / TONNE	STOCK	£ / TONNE
Sprat	203	Whiting	1017
Norway pout	90	Witch	975
Sandeel	188	Gurnard	399
Poor cod	200	Plaice	1049
Long rough dab	668	Starry ray	736
Dab	668	Haddock	1243
Herring	327	Cuckoo ray	736
Horse mackerel	498	Monkfish	2911
Lemon sole	2829	Cod	2015
Sole	6941	Saithe	924
Mackerel	770		

Figure 7.5. Economic value of catches in £ per tonne.

When the range-consistent scenarios were projected into risk reward space (Figure 7.6), we found that lower parts of the ranges performed better than the central estimates, which in turn performed better than the upper parts of the ranges. The single species FMSY estimates performed better than the multispecies ones. We were able to define an equivalent risk level for multispecies precautionary which was achieved about 50% of the time for the best management targets, but less than 10% of the time for the worst case.

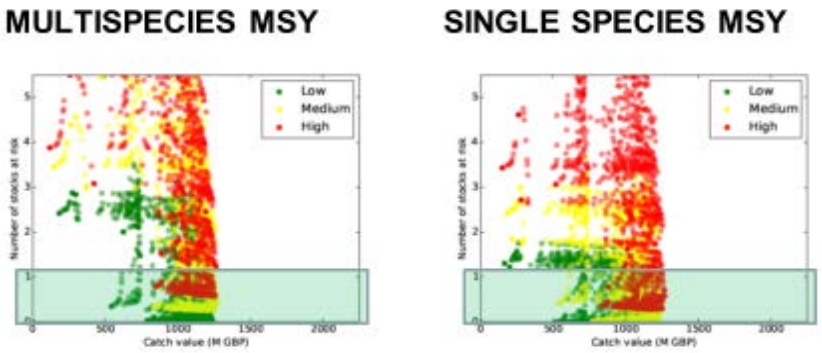


Figure 7.6. Risk/reward outcomes for multispecies FMSYs (left) and single species FMSYs (right). Red dots are for the upper limits, yellow for central estimates, and green for the lower limits, whilst the green zones at the bottom of the plots denote the multispecies precautionary estimates.

Even the best outcomes, relating to the lower limits of the single species FMSY ranges, are inferior to recent management outcomes in the North Sea (Figure 7.7).

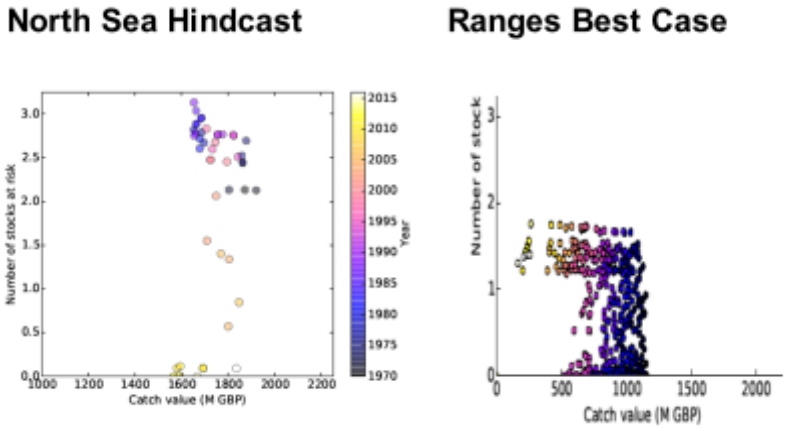


Figure 7.7. Risk ranges

We therefore conclude that "the probability that range estimates for the North Sea will be multispecies precautionary, given uncertainties in model parameters, management targets, and possible fleet scenarios is not more than 50%". And since the likely outcomes are mostly worse than the current situation, even though MSY ranges are an attractive concept, we need to rethink how they are applied before they can be a useful management aid in the North Sea.

7.4. GadCap: A gadget multispecies stock assessment model for the Flemish Cap. Afonso Pérez Rodríguez (IMR, Norway).

The changes occurred in total catches of cod, redfish and shrimp in the period 1988–2012, the opposite trends in the survey biomass indexes, and the apparent trophic interactions

in between all these three species motivated the project GadCap, intended to develop a gadget multispecies stock assessment model for the Flemish Cap, in the NAFO area 3M.

The model fit showed that after the very good recruitments of early 1990s in cod and redfish (Figure 7.8), which produced the increase in abundance and biomass, both stocks experienced a marked decline to the lowest levels ever registered in these populations by mid 1990s. Contemporaneously, the shrimp stock showed excellent recruitments since 1993, which produced the increase of the stock abundance and biomass. Since year 2000, a series of good recruitments raised the redfish stock to the highest values in the time period. The raising trend in redfish was followed by the decline in the shrimp stock, despite the good levels of recruitment during these years. Since year 2005 cod recruitments were good in comparison with those of years 1993–2004, and produced the increase in abundance and biomass. I years 2010–2012 cod recruitment were exceptionally high, which lead to the steep rise of the abundance and biomass of cod in the last years of the study period. This increase in cod population was in parallel to the decline of the redfish.

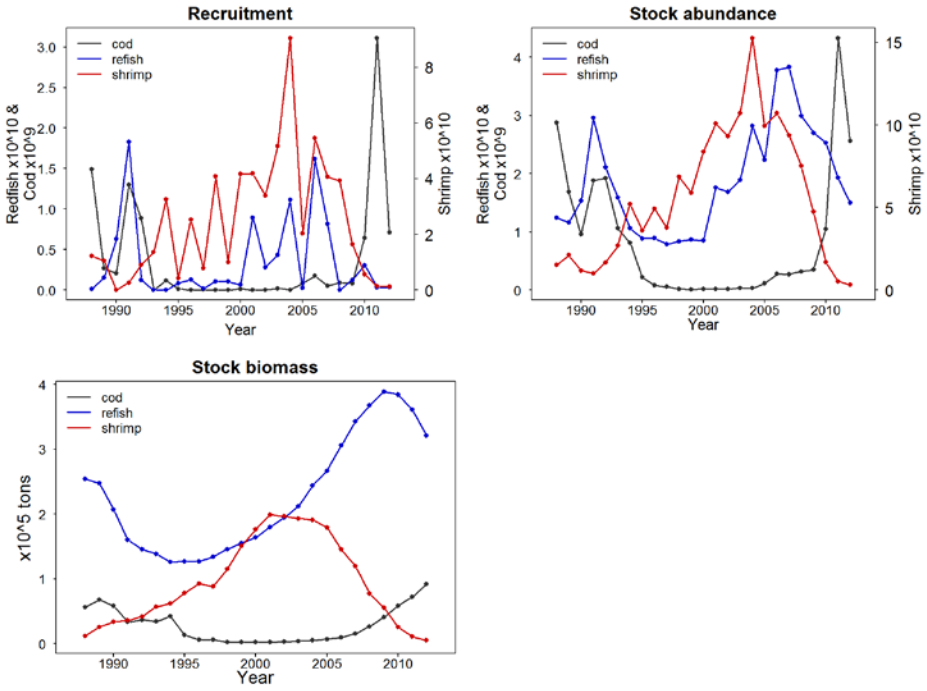


Figure 7.8. Annual estimates of recruitment, stock abundance and stock biomass for cod (black lines), redfish (blue lines) and shrimp (red lines).

The estimated predation and fishing mortality in cod (Figure 7.9) showed that cannibalism was the main source of mortality at ages 1and 2, during all the study period, while at age 3 only in the last years has shown similar values to fishing mortality. For the remaining ages fishing has been always the main source of mortality, which extreme values during the period 1988–1996. It is then showed by the model that the reduction of cod in the 1990s was due to the reduction of the population at all ages by cannibalism and fishing.

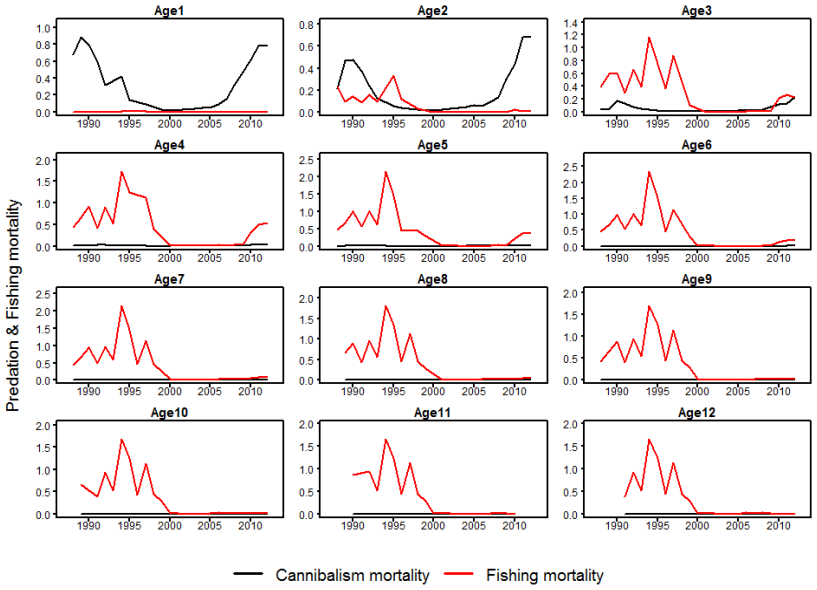


Figure 7.9. Predation mortality by cod and fishing mortality in the modelled cod stock by age.

Cannibalism in redfish was also a major source of mortality at ages 1 and 2 all over the study period, but it was especially important since 2000. Cod predation was the main source of mortality for ages 3 to 8 during most of the years. Fishing was the main source of mortality for ages 9 to 25+ during the 1990s, but in the last years predation has had a higher relevance.

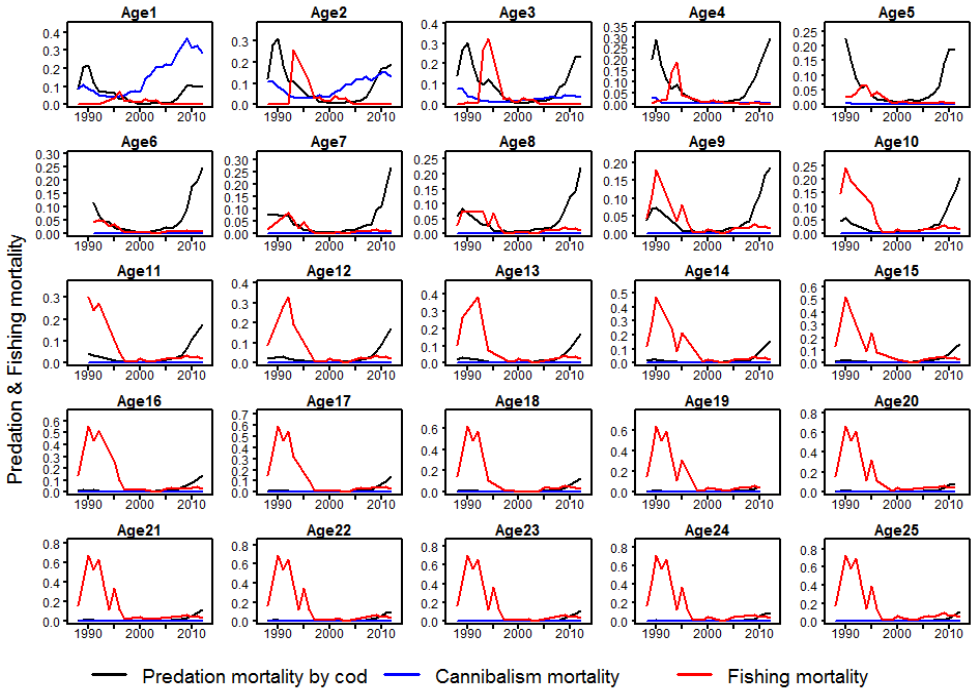


Figure 7.10. Fishing mortality and cod and redfish predation mortality by age in the modelled redfish stock.

In shrimp cod predation was the main source of mortality for most ages in the late 1980s, however, since 2000 predation by redfish removed the higher portion of population at ages 1–3, while fishing was the main source of mortality for ages 4 to 7 during most of the study period.

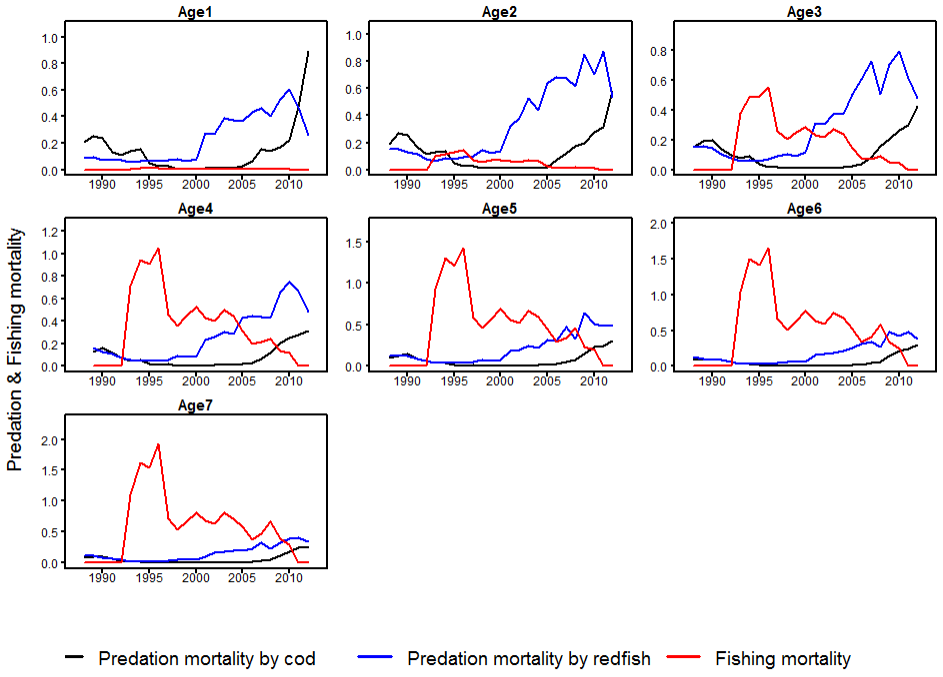


Figure 7.11. Predation mortality by cod (M_pred by cod), by redfish (M_pred by redfish) and fishing mortality by the shrimp trawl fleet by age in the modelled shrimp stock.

Conclusions

- Since 2005, predation mortality (including cannibalism) has been the main driver in the dynamic of all the three main commercial species in the Flemish Cap.
- In cod, predation (cannibalism) and fishing have occurred mostly at different ages in recent years (excepting age 3), while in redfish and shrimp they have worked simultaneously in a wide range of ages.
- Those years of excellent recruitment, cannibalism has been the main source of mortality both in juvenile cod and redfish, reducing significantly the expectative of increasing stock biomass.
- Predation by redfish and fishing have been the main factors driving to the collapse the shrimp stock. Predation by cod contributed to the decline of shrimp especially after 2007–2008.
- The increment of large cod in the stock, especially since 2010, has raised the predation mortality on redfish, and is the main factor inducing the decline of abundance and biomass in the last years.

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8. ToR G: Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM)

No contributions were made to this ToR in 2015.

9. ToR H. Work towards providing ecosystem advice consistent with species and technical interaction in mixed fisheries (preferably together with WGMIXFISH)

9.1. Combining stock, multispecies, and ecosystem level status determination criteria

Sarah Gaichas presented "Combining stock, multispecies, and ecosystem level status determination criteria: a worked example" by S. Gaichas, M. Fogarty, G. DePiper (NEFSC), G. Fay (SMAST), R. Gamble, S. Lucey, and L. Smith (NEFSC). This work explored alternative status determination criteria and reference points that could simplify fisheries management using a multispecies/ecosystem-based management procedure. There are four components to the management procedure: 1. a limit on total removals for the ecosystem; 2. an allocation of the total removals limit to aggregate species groups; 3. minimum stock size thresholds for individual species; and 4. guidance for optimizing the species mix (within aggregates) based on bio-economic portfolio analysis. In this procedure, "overfishing" criteria are applied only to aggregates of species at the ecosystem and group level, but "overfished" criteria apply at the species/stock level. Previous work using multispecies production models identified conditions where conservation and yield objectives could be balanced: aggregations of species with similar life histories, species interactions, and responses to environmental forcing supported the highest yields while minimizing risks that individual stocks dropped below biomass thresholds. Here,

we use a more complex size structured multispecies, multifleet simulation model (Hydra, described under ToR C) to explore the performance of the management procedure. Different species aggregation rules were applied (taxonomic, habitat, etc.) to form alternative groupings, and yield curves for the aggregate groups were constructed by sequentially increasing effort in each of the fleets (alone and simultaneously), while recruitment for each species varied stochastically around a function based on spawning stock biomass. The performance of individual species and each aggregate type was then compared with respect to yield and biomass objectives.

The first result of note is that both species interactions and environmental signals change yield over time, even with constant fishing effort in the three fleets. A baseline run with no fishing effort showed several species (e.g. elasmobranchs, cod, flounders) increasing as would be expected with no fishing mortality, but major prey species (herring, mackerel, silver hake) declining due to increased predation mortality from higher unfished predator biomass. Further, some species declined toward the end of the 50 year run due to increasing bottom water temperature on Georges Bank causing increased predation mortality via the temperature dependent consumption function in the model. Therefore, all runs were compared with the appropriate baseline (year 20 or year 50) rather than assuming a constant equilibrium condition.

Individual species yield curves driven by incrementally increasing effort in all gears together showed a variety of shapes, with some species having clear peaks in yield while others did not under the current model configuration (in particular the fleet specific combinations of size selectivity and catchability by species). Similarly, some species approached or exceeded lower biomass thresholds over the range of trial effort levels while others increased (herring, mackerel) due to release from predation mortality. Analysis of aggregations including the full 10 species system and 4 aggregates combining foraging guild and taxonomy showed the potential for maximizing biomass and economic yields given the constraint that no species may drop below a biomass threshold (here defined as 20% of unfished biomass in the ecosystem context – no fishing by any fleet). At the full 10 species system level for all fleets together, the yield curve was flat above about 50% of average observed effort. While biomass yield was maximized at the highest levels of simulated effort, these levels would not be permitted because several species fell below biomass thresholds. Furthermore, economic yield was highest at the lower effort levels because the species mix there was most valuable. Examining individual fleet yield curves revealed different tradeoffs between species biomass status, yield, and value, and suggested that alternative combinations of gears could result in about 15% more system yield within the constraint that no species fall below 20% B0. Of course, in reality fleet selectivities and catchabilities would not be constant over time so that further optimization of yield and value could be achieved given appropriate incentives.

Our results evaluate the tradeoffs between management simplicity, yield, and biomass status for the 10 species in the system. Overall we found that there are aggregate catch limits that can both maximize yield and value while conserving biomass. However, community composition and value trade off over a range of fishing effort. We consider this a starting point for further discussion with scientists, managers, fishermen, and other stakeholders in the region.

9.2. Principle Components Analysis (PCA) on the MIXFISH métier data used in North Sea mixed fishery forecasts to inform a minimum fleet aggregation for use in ecosystem models

Introduction

Currently the mix fisheries models used in the WGMIXFISH and the multi species models used in WGSAM are not interacting. Both model types are very complex and thus it is not currently possible to let either model feed into the other. A reduction in complexity is needed to circumvent the challenge of combining complex models. The primary input into the mixed fisheries model in the North Sea (Fcube) is the catch and effort data aggregated by fleet and métier (Ulrich *et al.* 2012). It has been suggested that the partial F from the métiers could be used in the multi species model SMS, to constrain the F on the individual species. However, the métier system currently contains 18 métiers distributed across 10 countries and 20 fleet types, giving rise to 105 distinct fisheries entering the mix fish models. Thus, an aggregation of métiers is needed if the partial mortality rates from the mixed fisheries models are to be transferred to the multi species models.

In the current study we applied principal component analysis to the catchability of each métier and fleets used in the mix fisheries models to investigate if fleets and métiers could be aggregated into a more manageable number of groups, while still contain the same information on catch composition and catchability of each species.

Method

Data on catchability and effort by fleet and métier was imported from the InterCatch database. Since the 2014 data was considered to be the most valid data, the year 2014 was selected for analysis. Stocks without assessment were removed from the dataset, along with fisheries that marked as significantly different from the North Sea fisheries.

To apply PCA, the catchability data (q) was transformed, as q varied between métier and fleet by a factor of 1000 or more. The transformation applied was:

$$q_{trans} = \frac{1}{\log(q)} * -1$$

The log transformation reduced the differences between catchabilities and the division was in order to change the log-effect on values less than zero, where smaller values becomes larger output values. The transformation was multiplied by -1 to change from negative to positive.

Following transformation, a PCA was applied on the catchability of each species as a function of métier. Fleet was not included into the model to obtain multiple samples of the individual métiers. To investigate the groupings in the PCA, a Hierarchical Cluster Analysis (HCA) was performed on the PCA output with eight groups chosen as the cut-off level for the clustering.

Subsequently, PCA was performed on the individual groups, adding effort to each métier, in order to evaluate the importance of each métier in the PCA and the coherence within each group.

The above analysis was used to evaluate if the groups were able to describe the joint fisheries of the included métier, and identify where groups consisted primarily of small métiers that could be added to other groups.

Finally, identical analysis was performed on 2013 data to evaluate the consistency of the groupings, with the exception of applying HCA on the 2013 data. Instead, 2014 groupings were applied to the 2013 data to evaluate if groups still maintained coherence. Longer term analyses were not performed, because the consistency of the data is questionable further back in time.

Results

Initial PCA analysis of the raw data (Figure 9.1.) showed a distinct difference in fishing properties between the North Sea and the Eastern Channel. Additionally, fleets and métiers operating in the ICES square 7D were distinctly different from the other fleets and métiers.

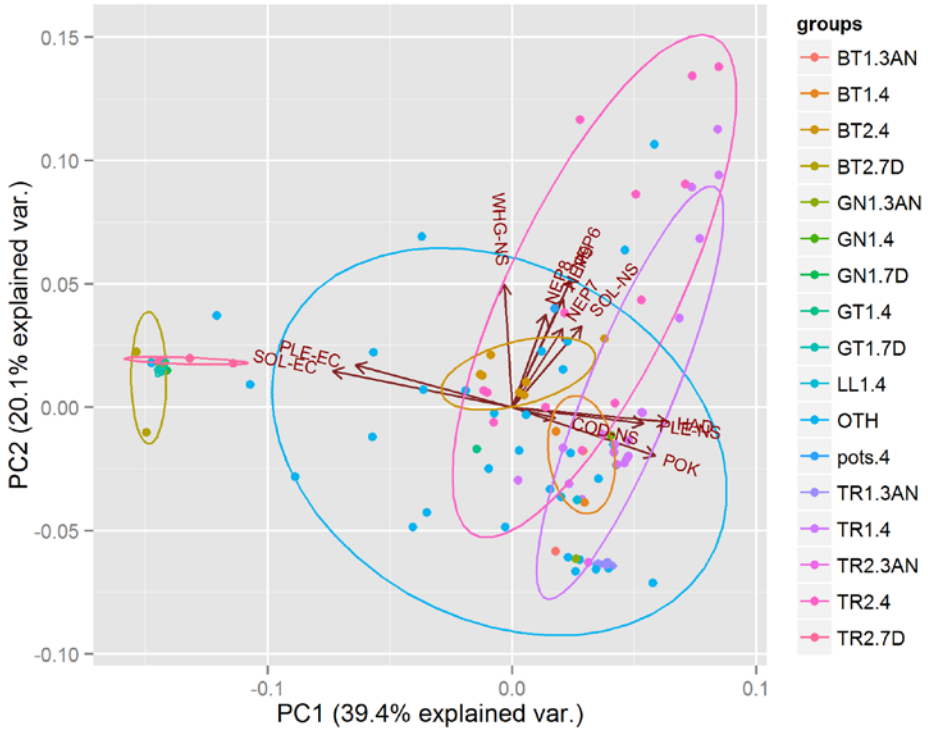


Figure 9.1. PCA results on initial dataset. Figure shows a plot of the two first principal components of the PCA analysis, with each dot representing a fleet and the coloring indicating the metier.

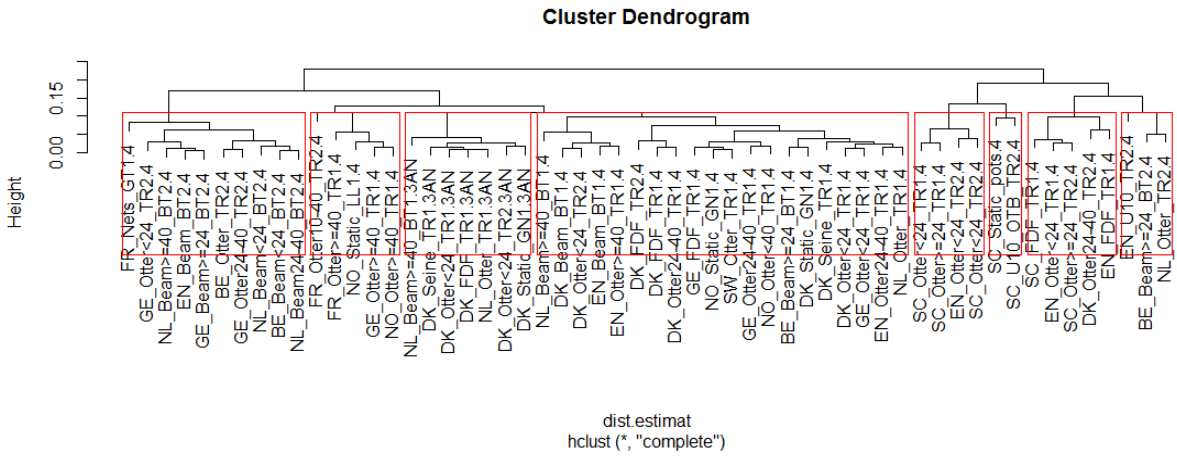


Figure 9.2 Hierarchical cluster analysis, demonstrating the clustering of fleets and metiers from the PCA

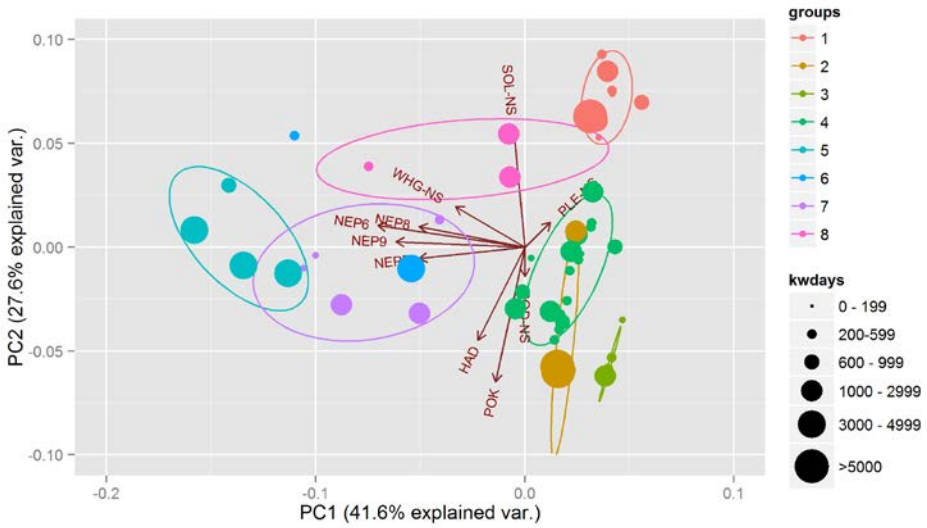


Figure 9.3. PCA results on the reduced data set. Each dot indicates a fleet and metier, with the size of the dot as weighted by effort in kW days. Coloring of the dots indicates the group the metier has been assigned to by the HCA.

To simplify the data and analysis, it was decided to remove the outlying métiers OTH, beam_OTH.4, BT2.7D, GT1.7D, TR2.7D and GN1.7D. Additionally, the stocks SOL-EC, PLE-EC was removed as these English Channel fisheries were distinct (both spatially and in fishing pattern) from the others. The Nephrops stocks NEP33, NEP5, NEPOTH-NS, NEP32, NEP34, NEP10 and TUR were removed as they did not have an assessment.

Rerunning the PCA and applying HCA yielded 8 distinct groups (Figure 9.2) with more or less coherence between each (Figure 9.3). Each group contained both large and small métiers. Detailing the PCA on each group demonstrated that most groups were coherent, with no major effect dividing the fleets and métiers internally in the groups.

Group 1 is mainly mixed fisheries métiers with one fleet/métier catching more haddock than the others, but not sufficiently to separate the fleet/métier onto a separate group. The second group is also mixed fisheries, with parts of the group targeting more flat fish than the others, however only to a small degree. Group 3, 7 and 8 are all homogeneous groups, with various degrees of shatter of the included fleets/métiers.

Group 4 is the largest group, containing a gradient between fleets/métiers targeting round fish and fleets/métiers targeting flat fish. To analyze if the gradient were divided enough to form two groups, then group 4 were subdivided into group 4.1 which contained all fleets/métiers with positive loadings on PC1 and a group 4.2 which contained all fleets/métiers with negative loadings on PC1. PCA on the two subgroups demonstrated a sufficient coherence in each, where group 4.1 were mainly focused on flatfish (sole and plaice), while group 4.2 were mainly focused on round fish.

Group 5 contains a little bit of everything, while group 6 only consists one large and one small fleet/métier, which are not comparable to other fleets/métiers.

To demonstrate consistency in the groups, the same group structure was applied to 2013 data, with equal removals of fleets and métiers. The PCA on the groups still demonstrated a suitable coherence within groups, to allow the assumption that groups are temporally coherent (Figure 9.1*)*

Discussion

Currently there are a considerable amount of métiers, which are used, among other things, as basis for the mixed fisheries models and advice. In order to incorporate mixed fisheries models into multi species models it has proven necessary to aggregate the métiers in order to simplify the information.

The current analysis demonstrated that it was possible to aggregate the North Sea fleets and métiers into 9 coherent groups (plus several outliers), each group containing a various number of fleets and métiers. Each group was had a fair amount of internal coherence, with no significant outliers. This indicates that it should be possible to simplify the existing métier system by aggregating into groups of similar métiers, and further that this can reduce the number of groups that need to be considered to a manageable set that could be incorporated into multispecies models such as SMS.

It should be noted that this analysis was conducted on 2013 and 2014, before the landing obligation comes into force in the North Sea. It is possible that changes in fleet behaviour resulting from the landing obligation could change the grouping identified here. The analysis should therefore be repeated once data on post landing obligation fishing patterns are available.

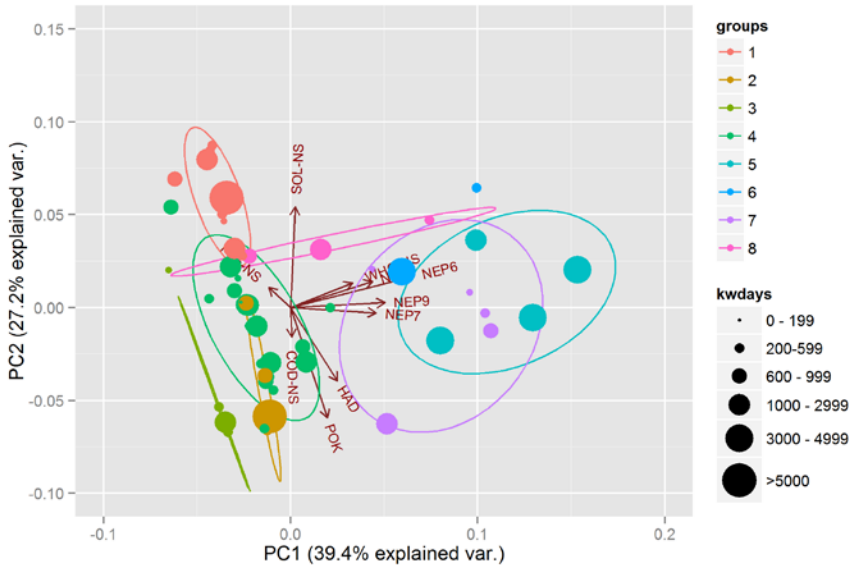


Figure 9.1. PCA on 2013 catchability data, with identical groupings at identified by HCA on the 2014 data. Color indicates group and dot size indicates effort of the individual fleet/metier.

9.3. Multispecies Interactions in an Idealised 4-fleet fishery of the North Sea – Robert Thorpe, Paul Dolder, Stuart Reeves, Peter Robinson, Simon Jennings

We presented results from a multispecies and multifleet model of the North Sea fish community, which looked at the trade-offs between the otter and beam fleet, and the ability or otherwise of fish community indicators to assist in managing towards a favourable risk/reward profile and hence achieve multispecies MSY.

The experimental design is shown in Figure 9.5 below:

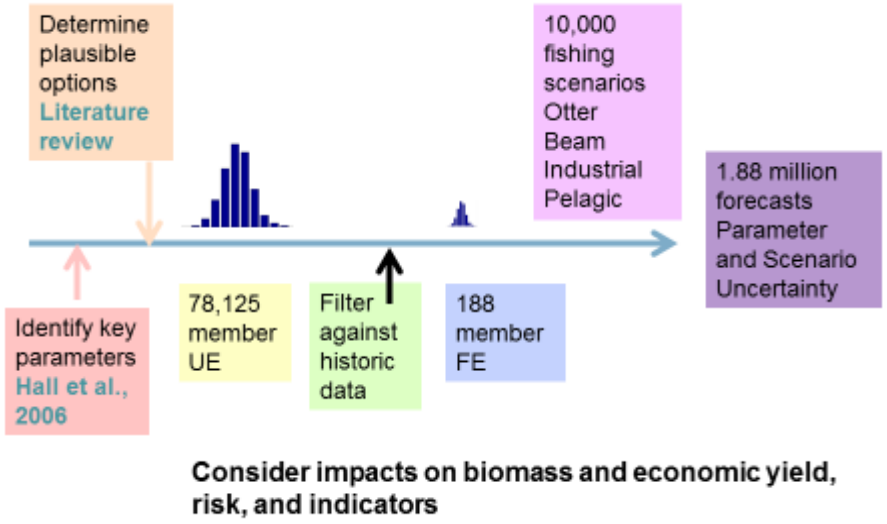


Figure 9.5. Schematic of the experimental design of the 4 fleet experiment. 10 000 fleet scenarios were considered, covering 10 different effort levels for each fleet from zero up to twice the average effort levels of the 1990–2010 period.

Fleet fishing mortality at average 1990–2010 effort was as in the study in ToR F, as was the economic value of the catch. We look at the trade-offs that have to be made between the beam and otter fleets, assuming 1990–2010 from pelagic and industrial trawlers, for a) tonnage yield, b) economic yield, c) risk of stock depletion, and d) performance of the large fish indicator.

We find the fairly typical result that it is not possible to maximise yield (tonnage or £) whilst keeping risk to a multispecies precautionary level (below an average of 1.05 stocks recruitment-impaired by fishing for the 21 stock fish community – Figure 9.6).

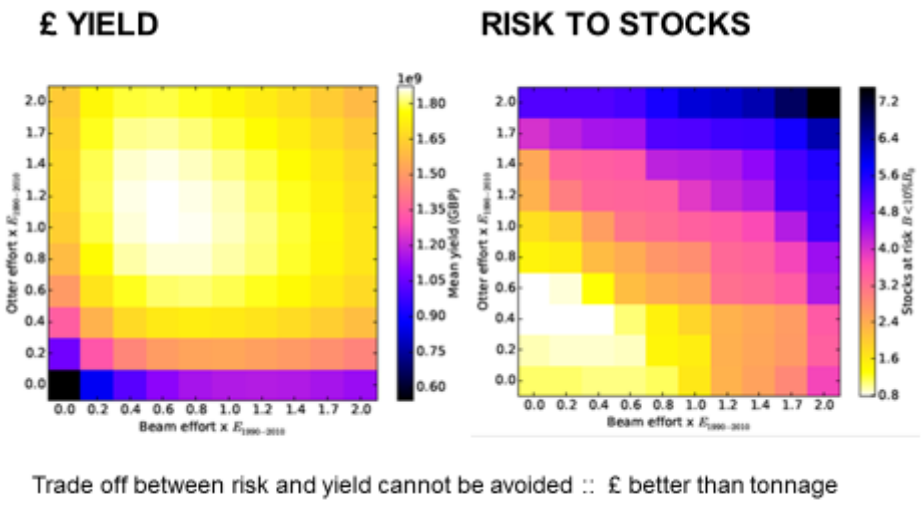


Figure 9.6. Trade-offs between beam and otter fleet for (left) economic yield, and (right) overall risk of stock impairment.

Whilst it is not possible to maximise yield and achieve multispecies precautionary levels of risk (R<1.05), a good precautionary yield of around 90% of the maximum possible can be obtained.

We also considered the relationship between community indicators and risk by fleet. Only results for the Large Fish Indicator (or LFI) are shown (Figure 9.7), but they are similar for all indicators considered so far, including mean length (ML), mean maximum weight by biomass (MMW), and slope of the size spectrum (SSS).

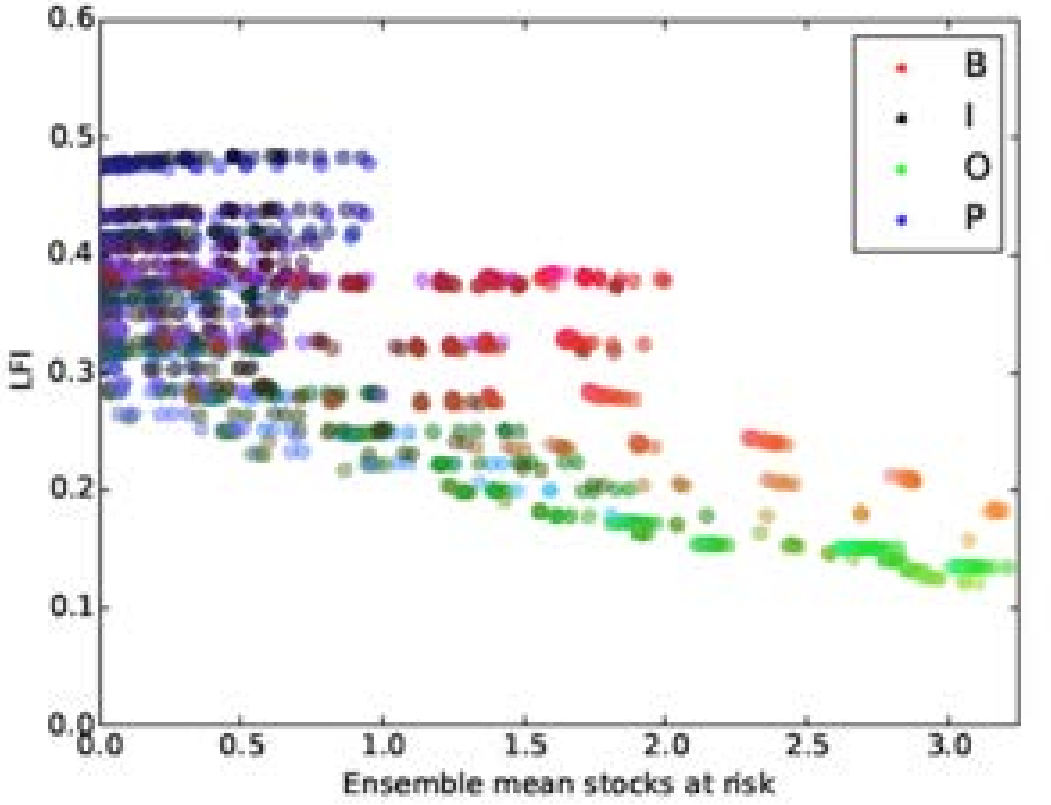


Figure 9.7. Relationship between ensemble mean LFI and ensemble mean number of at risk stocks for the various fleet scenarios. Scenarios are colour coded according to the relative effort of the fleets, red for beam, green for otter, blue for pelagic, and black for industrial.

For the otter fleet (green) there is a good strong near-linear relationship between the LFI and level of risk, this relationship deteriorates to moderate for the pelagic fleet and is poor to non-existent for the industrial and beam trawl fleets.

Using the 10 000 fleet fishing scenarios, we constructed a pattern-match hindcast in which each of the years 1970–2014 (and the estimate for 2015) were represented by the scenario member which was closest to it in terms of the estimated fishing mortality on the 21 model stocks. The hindcast is shown in Figure 9.8.

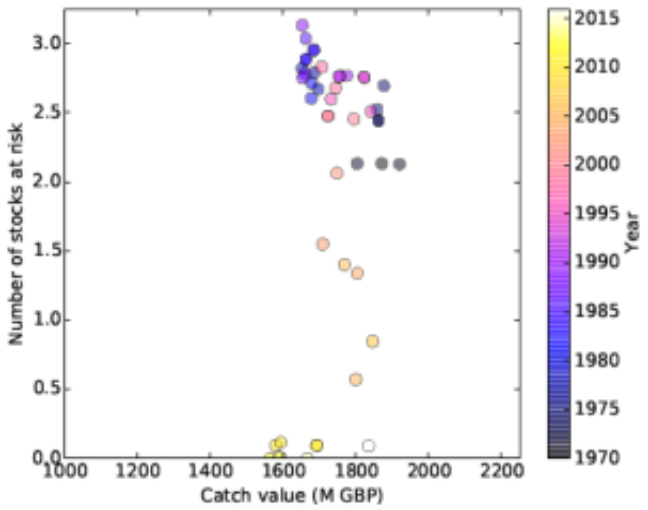


Figure 9.8. Pattern-match hindcast of historic North Sea fishing, using the analogue from the 10 000 fleet fishing scenarios which most closely represents each year from 1970 to 2014, with an estimate for 2015.

We can see how the period from 1970 to around 1985 was associated with a deteriorating management situation with increasing risk and decreasing yield, followed by stabilisation, and then by a rapid reduction in the risk of stock impairment from the mid-1990s onwards. The inference is that the current regime has succeeded in improving the status of North Sea fisheries, and that these fisheries are currently being exploited in way which approximates to multispecies FMSY.

We also considered the impact of gear changes by considering an additional scenario set using an idealised fleet set up in which each stock was caught by one fleet and one fleet only (Figure 9.9).

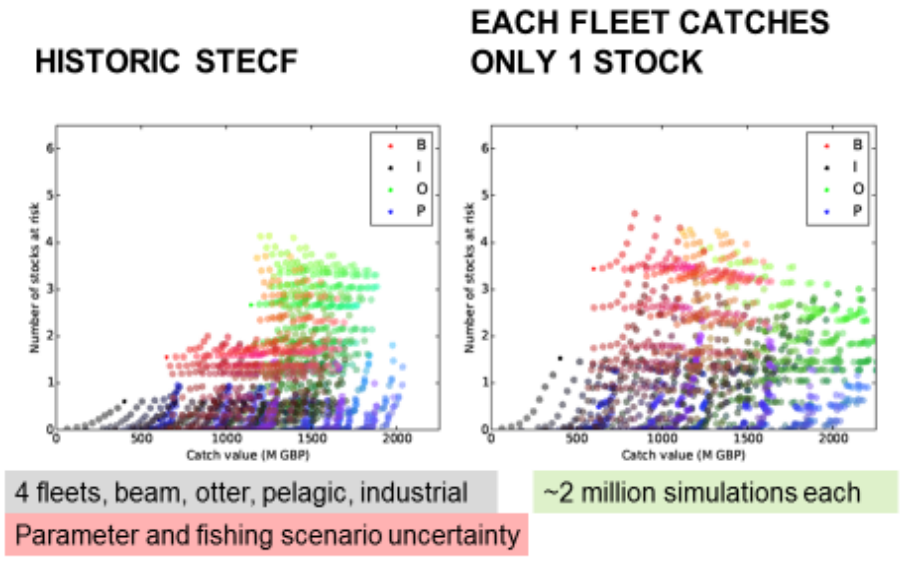


Figure 9.9. Risk/reward spreads for (left) fleets with historic catch patterns from STECF data, and (right) idealised fleets where each stock is caught by only one fleet.

The idealised fleets align with stocks and so there are no technical interactions, and other things being equal, they should perform better. This is true for the otter fleet (green) and to a lesser extent the pelagic fleet (blue). The industrial fleet (black) performs marginally worse, but the performance of the beam fleet deteriorates significantly. Overall though, the estimated multispecies MSY (rightmost region where risk R<1.05) increases by 5–10%. These results, particularly the reduction in performance of the beam fleet, show the importance of both biological and technical interactions, and indeed demonstrate that it is possible for the former to override the latter. This methodology could be used to price the costs and benefits associated with redesign of gear.

10. Response to Requests to WGSAM

10.1. HAWG request to compare natural mortality estimates

HAWG has recommended a comparison of the similarity of ecosystems across the HAWG stocks (Greater North Sea, Celtic Seas, Baltic Sea) in particular with respect to estimation of natural mortality (predator fields and dynamics). WGSAM decided to make a metanalysis of the level of M at age, the interannual variability and the degree to which different ages experience similar changes in natural mortality.

10.1.1. North Sea

Natural mortalities of North Sea herring from 1974 to 2013 are available from the 2015 SMS key run (Section 3). Average M and standard deviation of M by age is given in Table 10.1 and the correlation between annual values of different ages are given in Table 10.2. The mean biomass of herring in the North Sea over the time period is 1.9 million ton, and the average total biomass of the main predators whiting, cod, saithe and hake is 1.2 million ton, and the average SSB is 0.5 million ton. This gives a ratio of herring to predator biomass of 1.6 when using total predator biomass and 3.7 when using spawning biomass only. There was a low but significant positive correlation between the average natural mortality of herring and both predator biomass and SSB (r^2=0.10 and 0.33, P=0.0414 and <0.0001, respectively).

Table 10.1. Average M, standard deviation of M, min and max M recorded for herring in the North Sea.

Age	Average M	sd M	min M	max M
0*	0.79	0.08	0.64	0.94
1	0.65	0.09	0.48	0.87
2	0.36	0.05	0.27	0.48
3	0.33	0.04	0.24	0.39
4	0.30	0.04	0.23	0.36
5	0.28	0.04	0.22	0.35
6	0.27	0.04	0.21	0.35
7	0.25	0.04	0.19	0.33

*** Age 0 M covers only 1/7 to 31/12.**

Table 10.2. Correlation between natural mortality of different groups. Upper lines: correlation. Lower line: P(correlation=0).

Age	1	2	3	4	5	6	7
0	0.56374	0.57676	0.55867	0.57905	0.58452	0.63028	0.62375
	0.0002	<.0001	0.0002	<.0001	<.0001	<.0001	<.0001
1		0.64966	0.46042	0.47129	0.41476	0.42473	0.32796
		<.0001	0.0028	0.0021	0.0078	0.0063	0.0388
2			0.87619	0.83452	0.78527	0.79292	0.71838
			<.0001	<.0001	<.0001	<.0001	<.0001
3				0.93645	0.90083	0.91255	0.84012
				<.0001	<.0001	<.0001	<.0001
4					0.96621	0.95217	0.87323
					<.0001	<.0001	<.0001
5						0.96802	0.92404
						<.0001	<.0001
6							0.94922
							<.0001

10.1.2. Baltic Sea

Natural mortalities of Baltic Sea herring from 1974 to 2011 are available from the 2012 SMS key run (WGSAM 2012). Average M and standard deviation of M by age is given in table 10.3 and the correlation between annual values of different ages are given in table 10.4. The mean biomass of herring in the Baltic Sea over the time period is 1.2 million ton, and the average total biomass of the main predator cod is 0.34 million ton, and the average SSB is 0.17 million ton. This gives a ratio of herring to predator biomass of 3.5 when using total predator biomass and 8.2 when using spawning biomass only. There was a low but significant positive correlation between the average natural mortality of herring and predator biomass but not when using SSB (r^2=0.11 and 0.02, P=0.0463 and 0.3611, respectively).

Table 10.3. Average M, standard deviation of M, min and max M recorded for herring in the Baltic Sea.

Age	Average M	sd M	min M	max M
0*	0.16	0.05	0.10	0.27
1	0.31	0.08	0.24	0.50
2	0.29	0.05	0.24	0.43
3	0.27	0.04	0.23	0.36
4	0.26	0.03	0.22	0.33
5	0.25	0.02	0.21	0.32
6	0.24	0.02	0.22	0.32
7	0.23	0.02	0.21	0.30

*** Age 0 M covers only 1/7 to 31/12**

Table 10.4. Correlation between natural mortality of different groups. Upper lines: correlation. Lower line: P(correlation=0).

Age	1	2	3	4	5	6	7
0	0.96512	0.81137	0.69393	0.44593	0.27756	0.06714	-0.22398
	<.0001	<.0001	<.0001	0.0050	0.0916	0.6888	0.1764
1		0.88227	0.78463	0.51868	0.39498	0.05111	-0.20895
		<.0001	<.0001	0.0008	0.0141	0.7606	0.2080
2			0.95261	0.70798	0.53082	0.19335	-0.06626
			<.0001	<.0001	0.0006	0.2448	0.6927
3				0.83547	0.68690	0.36261	0.12365
				<.0001	<.0001	0.0253	0.4595
4					0.76177	0.61485	0.47250
					<.0001	<.0001	0.0027
5						0.70101	0.63400
						<.0001	<.0001
6							0.81319
							<.0001

10.1.3. Georges Bank

Natural mortalities of Georges Bank herring from 1978 to 2007 are available from a multi-species statistical catch-at-age model (Curti, pers. comm). Average M and standard deviation of M by age is given in table 10.5 and the correlation between annual values of different ages are given in table 10.6. The mean biomass of herring over the time period is 0.069 million ton. Herring is consumed by a wide array of predators, but the average total biomass of the most dominant predator (cod) is 0.092 million ton. This gives a ratio of herring to predator biomass of 0.74.

Table 10.5. Average M, standard deviation of M, min and max M recorded for herring at Georges bank.

Age	Average M	sd M	min M	max M
1	0.52	0.20	0.27	0.91
2	0.49	0.24	0.23	1.01
3	0.35	0.18	0.18	0.83
4	0.27	0.14	0.15	0.65
5	0.22	0.11	0.14	0.58
6	0.18	0.09	0.11	0.45

Table 10.6. Correlation between natural mortality of different groups. Upper lines: correlation. Lower line: P(correlation=0).

Age	2	3	4	5	6
1	0.87756	0.78593	0.73756	0.71671	0.67765
	<.0001	<.0001	<.0001	<.0001	<.0001
2		0.94464	0.87334	0.82000	0.77209
		<.0001	<.0001	<.0001	<.0001
3			0.96772	0.91979	0.88025
			<.0001	<.0001	<.0001
4				0.97291	0.94025
				<.0001	<.0001
5					0.98034
					<.0001

10.1.4. Size spectra model results for the Celtic Sea and North Sea

The values analysed for the North Sea, Baltic Sea and Georges Bank are all hindcasts of ecosystems where herring predators have been severely depleted during part of the time-series. In a system where predator abundance was substantially higher, these natural mortalities may change substantially. To investigate this, we compared the natural mortalities from the 3 hindcast models with predictions from the Lemans model. This model predicts natural mortality at length, and these were transformed to natural mortality at age by using the weight at age of herring in each system (HAWG 2015), a length weight

relationship and a smoothed relationship between length and natural mortality from model output.

10.1.5. Comparison across areas

In general, the hindcasted average natural mortalities were very similar over the three areas (Figure 10.1). In spite of herring being an important forage fish in all three areas, average natural mortality beyond age 3 was below 0.35 for all three stocks. The variability varied greatly between areas, with Georges Bank having the most (up to 4.6 times difference between the highest and lowest observed) and the North Sea the least variable natural mortalities for herring (less than 1.8 times difference between the highest and lowest observed). The change in Georges Bank mortalities were linked to a substantial decrease in the biomass of herring predators.

Given that the natural mortalities are very similar across stocks, it is probably a reasonable assumption that the natural mortalities do not vary greatly between areas unless the state of the predatory stocks varies greatly compared to the systems investigated here which all have exploited predator stocks. There was no link between natural mortality and e.g. the biomass of herring relative to that of predators and it was not possible to use very simple relationships with predator biomass to reliably predict annual variation in natural mortality.

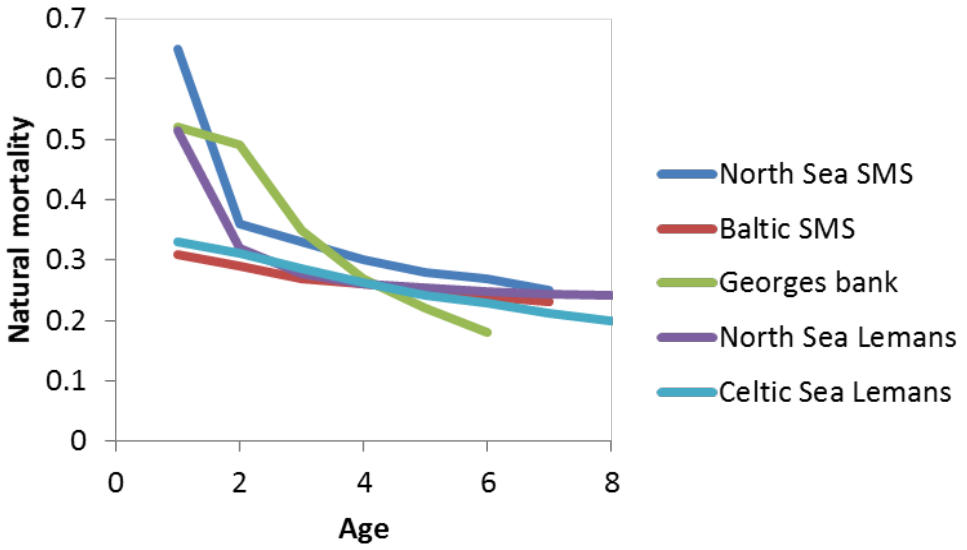


Figure 10.1. Natural mortality at age for different ecosystems from multispecies modelling based on statistical catch at age model hindcasts (North Sea SMS, Baltic Sea SMS and Georges Bank) and forward simulations in the Lemans model.

10.2. WGBIOP relevance to WGSAM

The Working Group on Biological Parameters (WGBIOP) is a new group that supports the development and quality assurance of biological parameters used in assessments and advice (ICES 2015). At its core it continues the work of PGCCDBS (ICES, 2014) which dealt with the quality assurance of biological parameters (primarily fish age and maturity) through calibration workshops and exchanges. However, WGBIOP recognises the

need to expand its remit to include new biological parameters needed to support multi-species modelling and integrated ecosystem assessments (IEA). Therefore, the first 3-year period for WGBIOP will be focused on identifying new or emerging biological parameters and assessing their quality in terms of sampling and estimation.

To complete this task, WGBIOP envisages producing a database to document key parameters and related information such as available datasets, computational methods, uncertainty estimates and quality indicators. This will hopefully be a useful resource for modelling and assessment groups and sampling design/data collection groups to indicate what data are available, the quality of that data and priorities for future data collection.

For this database to be of most use, WGBIOP has contacted WGSAM to begin identifying the key parameters that need to be prioritised by WGBIOP. Parameters identified during discussions fell into two clear groups: parameters currently in use that would benefit from greater data coverage and quality and emerging parameters that are starting to be included in multispecies models (these are detailed below). Furthermore, 3 perspectives came out of the discussions which were the continued need for data used in single species assessments to be as good as possible, that data needs to be collected on a per species basis even if some species are currently assessed together and that data should be available on a quarterly basis as much as possible. An indication of the priorities for future data collection is detailed in WGSAM 2012 report (ICES, 2012).

References

ICES. 2012. Report of the Working Group on Multispecies Assessment Methods (WGSAM). ICES CM 2012\SSGSUE:10.

ICES. 2014. Report of the Planning Group on Commercial Catches, Discards and Biological Sampling (PGCCDBS). ICES CM 2014\ACOM:34.

ICES. 2015. First Interim Report of the Working Group on Working Group on Biological Parameters (WGBIOP). ICES CM 2015\SSGIEOM:08

Parameters currently used

- Stomach data
    - Updated data needed for North Sea
    - Cover a larger range of species. Sample older fish as stocks recover.
    - Sampling at different times during the year (availability of prey differs through the year)
    - Alternative data sources for whale diet - scat collection, stomachs from hunters and strandings. Subsurface feeding remains relatively unknown.
- Body condition
    - Need continued sampling of body condition indicators - weight-at-age, weight-at-length, weight of liver, stomach etc.
    - Weight-at-length data needed on important predators (not just assessed species)
- Predation
    - More recent M0 and M2 values needed
- Tagging studies

    - Useful when aging is unreliable and to validate cheaper methods
- Biogeochemistry
    - Oxygen concentration - CTD sampling
- Life history parameters
    - Need for accuracy in derived life history parameters and quantification of variability/uncertainty
    - How do energy requirements, consumption, swimming speed relate to body length. Identify results from lab studies.
    - Genetic markers associated with life history traits

Future/emerging parameters

- Lower trophic levels
    - Phytoplankton and zooplankton abundance, chlorophyll.
    - Information needed specifically on key species (e.g. Calanus)
    - Benthic communities
- Recruitment
    - Larval survival - drift modelling in addition to temperature and zooplankton biomass
- Spatial
    - Migration – e.g. how much mackerel and horse mackerel in the North Sea?
    - Drivers of distribution – e.g. Hake - range increasing because of temperature increases or falling food availability?
- Acoustic surveys
    - E.g. Krill biomass, pelagic species
    - Can give different abundance estimates compared to other methods
- Climatic/environmental data
    - Subsurface temperature data – important for growth and feeding

Annex 5: Workshop on prey-dependent growth

11 November 2015, Marine Biological Laboratory, Woods Hole, USA

Background

Multispecies simulation models have historically been more focused on predation-induced mortality than on modelling the impacts of prey availability on predator growth. Such "models of intermediate complexity" ("MICE") are, however, increasingly tackling the issue of prey-dependent growth. The recent example of poor condition cod in the Baltic is one example of a region where this has become an area of concern. More generally there is a desire to integrate variable growth into the models in a mechanistic manner.

A workshop was held during WGSAM 2015 in order to take advantage of the presence of European and American multispecies modelers. There were several presentations on the difficulties of parameterizing mechanistic models, and several on more pragmatic approaches, followed by a discussion on how best to proceed with this sort of work.

Introduction

At present multispecies "MICE" models typically model stock trends and predation induced mortality in a realistic manner, while ignoring the effects of prey abundance on predator condition and growth. This approach allows for models to be formulated and tuned to data, and be able to address a range of fisheries questions. However it limits the range of questions which can be addressed, and in particular limits the ability of such models to accurately represent the outcomes of multispecies or ecosystem modelling. In contrast simulation models (such as Atlantis) have prey impact on predators fully incorporated, but are not tuned to the data, and therefore have less accurate representation of stock trends.

The session opened with an overview of why such modelling is difficult. Data, especially diet data, is difficult and expensive to collect and often subject to high variability and prone to bias from number of sources. At the same time, obtaining time-series estimates of all the main preys in a system is typically not possible, especially for the many poorly sampled invertebrate prey. As a consequence the data support for modelling overall consumption and how this relates to prey availability is often poor, and available datasets often cover a rather short time span. Even when such consumption estimates can be made, the relationship between large-scale food availability and predator growth is often non-linear and difficult to quantify. One area that was highlighted as a source of difficulty was spatial distributions, and the match-mismatch between predator and prey. Often this occurs on a spatial and temporal scale that is not well resolved in the available survey data. These difficulties in data collection and spatial and temporal understanding compound to make parameterizing the link between prey and growth a non-trivial process.

The inability to make the bottom-up link from prey to predators is of limited importance in single species assessment, or single species assessment with imposed predation mortality (M2 values). However it does severely limit the ability of a model to represent multispecies or ecosystem wide management, where changes in forage fish stock would be expected to impact many of the main target fish species. This is moving from theory to

management with, for example, an explicitly multispecies HCR for the NEA cod being part of the HCR evaluation planned for 2016. There is therefore pressure to both find ways of parameterizing the mechanistic formulations of prey-related growth, and to explore more pragmatic alternatives.

Specific presentations

Growth modelling in Atlantis, considering mobility of predators

Isaac Kaplan presented Atlantis end-to-end modelling approach for handling prey dependent growth. The Atlantis framework developed by Dr. Beth Fulton at CSIRO (Fulton *et al.* 2011) is a full simulation model, and has predator growth as a function of consumption, but also temperature and movement. Growth and size-at-age are emergent properties which must be carefully checked in Atlantis; for instance Atlantis outputs that predict very low growth may suggest underestimates of consumption, poor overlap of predator and prey, or mis-specification of size of recruits. Thus, Atlantis is a complex simulation model which may illustrate both advantages and pitfalls in modelling prey dependent growth.

A case study from California Current Atlantis model illustrates that parameterization of movement has a large impact on model predictions of growth, via availability of prey to predators. When sardine were depleted but predators were highly (perhaps artificially) mobile and could access increased krill abundance, predator growth and size-at-age increased to very high levels (**Figure AtlantisExcessiveGrowth**). Reducing predator mobility led to growth and size-at-age that better matches observations (**Figure AtlantisModerateGrowth)**. With reduced mobility, predators did not increase in size-at-age or biomass when sardine were depleted. Simple conclusions from this are 1) in spatial models predator movement rules can influence prey consumption, and subsequent growth. 2) If size-at-age or growth are emergent properties of the model, these patterns need to be checked in the output.

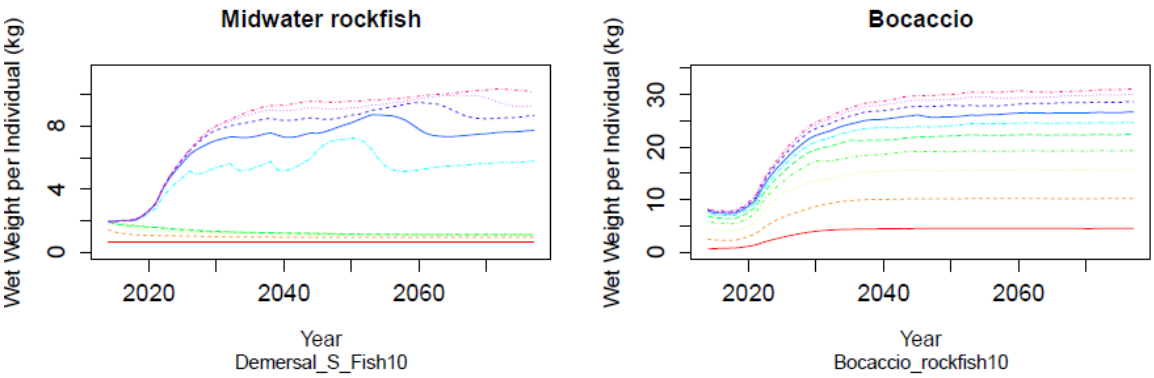
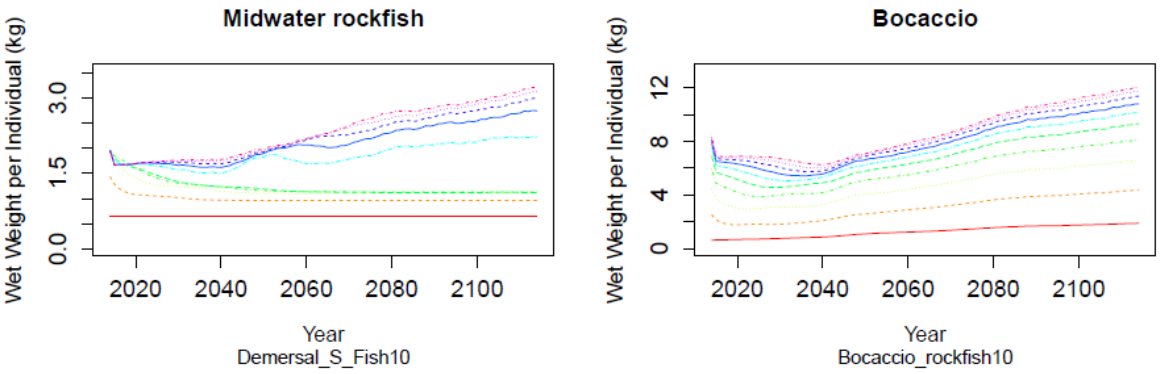


Figure AtlantisExcessiveGrowth. Weight-at age-through time for two Sebastes species, in the case where predators are highly mobile. Age classes are rainbow colored from red (youngest) to violet (oldest).

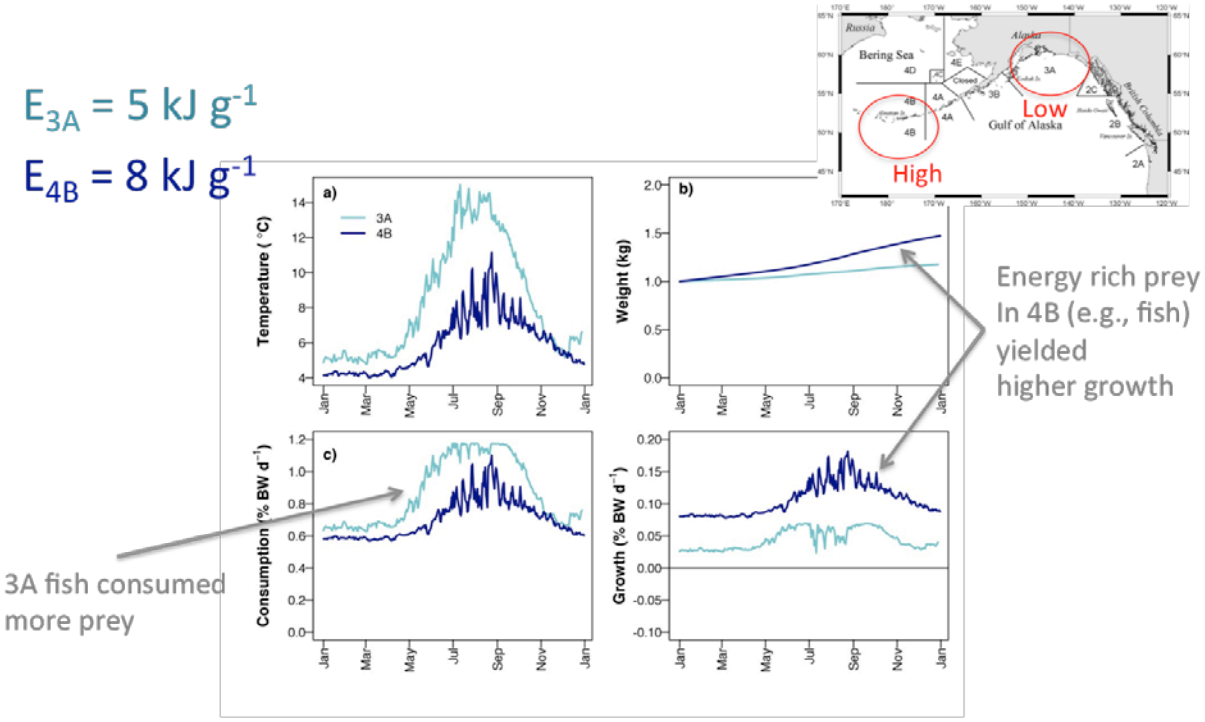


FigureAtlantisModerateGrowth. Weight-at age-through time for two Sebastes species, in the case where predators are less mobile. Age classes are rainbow colored from red (youngest) to violet (oldest).

Sarah Gaichas presented a list of multispecies and ecosystem models at the NEFSC that can and cannot answer the question if more herring were left in the system, would it benefit other predators. Atlantis, Kraken, and the independent implementation of EwE (Rpath) incorporate prey dependent growth now, while the age and size structured multispecies models do not. Kraken was used in simulations to evaluate tradeoffs between marine mammal and fish predators and fishery removals and incorporated a very basic form of prey-dependent population growth simply by allowing both positive and negative species interaction terms (Smith *et al.* 2015) This could form one end of a spectrum of complexity for incorporating prey dependent growth, but it has not yet been tested in estimation mode, primarily because both simulation testing and model inter-comparisons were with the SCAA and Hydra, which do not incorporate prey-dependent growth. SCAA takes a weight at age time-series as input and does not attempt to estimate growth at all. Hydra uses growth functions parameterized outside the model to specify the probability of growing out of one length category into the next. It would be a major rework of Hydra to have dynamic updating of growth based on consumption estimates (although consumption is already estimated by the model) because as a size structured model, growth of individual species determines the model timestep (the timestep is the time taken by the fastest growing species to get through its fastest-growth (usually first) length interval). Therefore it would be theoretically possible to be changing model timesteps during a run—this would have to be constrained. However, Hydra is already set up to incorporate covariates on both its growth functions so some form of prey dependent growth could be incorporated as a covariate based on empirical analysis. Model equations were presented and discussed.

Sarah Gaichas presented Kirstin Holsman's contributed slides on bioenergetics modelling for Pacific halibut. Otolith analyses show a decline in Pacific halibut size-at-age between 1977 and 1992, with larger Pacific halibut found in the western Aleutian Islands (4B) than east (3A) in both years. Temperature in the west may be more favorable for summer growth as conditions in the east often approach or exceed thermal optimum. Halibut in the west foraged at a higher rate than fish in the east and consumed higher quality prey. Bioenergetics modelling revealed that growth trajectories are established early, and reduced foraging efficiency, increased metabolic demand, and reduced prey quality further

contribute to reduced growth and size-at-age for Pacific halibut (Figure HOLSMAN). More information on the MICE model in development in Alaska is in (Holsman *et al.* 2015).



Holsman Figure Model results for two hypothetical 1 kg fish from 3A (light blue) and 4B (dark blue) management areas, where the p-value was set to 0.4 and prey energy densities were set to 5 and 8 kJ g^{-1} for 3A, and 4B respectively. Fish energy density is assumed to be 20.05 kJ g^{-1}: a) daily mean temperature values from NOAA mooring buoys in each area, b) model estimated weight at the end of the simulation period (365 days), c) daily prey consumption as percent body weight per day (g prey per g fish per day), and d) daily growth as percent body weight per day (g fish per g fish per day).

Analysis of the influence of water temperature and food availability in the Flemish Cap cod growth rate. Alfonso Pérez Rodríguez (IMR, Norway)

The Flemish Cap, a deep water fishing ground located in the Northwest Atlantic, in the NAFO (Northwest Atlantic Fisheries Organization) area 3M, has experienced important variations in community composition and water temperature since late 1980s. In the mid 1990s the Flemish Cap cod stock collapsed, which was followed by the increase of other stocks in the bank, which are eventually prey items for cod, like wolffishes *Anarhichas sp.*, the Northern shrimp *Pandalus borealis* and redfish *Sebastes sp.* Contemporaneously, the early-mid 1990s was the coldest period since 1960, while since 2000 temperatures raised to the highest registered values.

During this period marked changes in the average size at age in the cod population were observed. To evaluate the effect of water temperature and food availability on fish growth, these factors were compared with the growth rate by age, which was obtained by isolating the parameter K from von Bertalanffy growth model:

$$K_a = -\frac{\ln\left(1-\left(\frac{\Delta L_i}{L_\infty - L_i}\right)\right)}{\Delta t} \qquad (2)$$

Where L_i is the length at age *a-1* in year *y-1*, and ΔL_i the difference in relation to length at age *a* in year *y*.

Assuming that no changes in prey preference nor prey switching has occurred in the Flemish Cap cod (which could be an acceptable assumption in the Flemish Cap over long time periods), the proportion of each prey in the stomach was considered to be appropriate to estimate a food availability index. Averaging over time the percentage of a given prey in the diet of cod it is obtained a proxy with joint information of both the average prey biomass in the system and the prey preference (average prey availability). Multiplying this by the standardized time-series of prey abundance (0 to 1) an index of the prey availability over time is obtained (biomass through time x average prey preference). Finally, adding up the availability index over all preys a global food availability index is obtained.

The data employed in the present study were collected during the International European Union bottom trawl surveys, conducted annually on the June-July period since 1988. Data on temperature and salinity was collected throughout the water column, from surface to the bottom, using conductivity-temperature-depth cast (CTDs). Cod stomach content sampling in the EU Flemish Cap survey covered the period 1993–2012. Prey abundance indexes were obtained from the EU survey by means of the swept area methods for prey species like juvenile cod, redfish, Northern shrimp and other species like wolffishes. In addition, index of abundance for invertebrate zooplankton, like Hyperiids and Euphasiids, was obtained from the Continuum Plankton Recorder (CPR) survey marine monitoring program of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS; website: http://www.sahfos.ac.uk) during the period 1991–2012.

The average temperature in the bottom of Flemish Cap during the July survey showed a marked decline in the early 1990s, followed by an increasing trend since then, which lasted until 2008, when a stable period is identified (Figure 1). The increasing trend is dotted with sudden increases of temperature, like those observed in 1999–2000, 2005 or 2009.

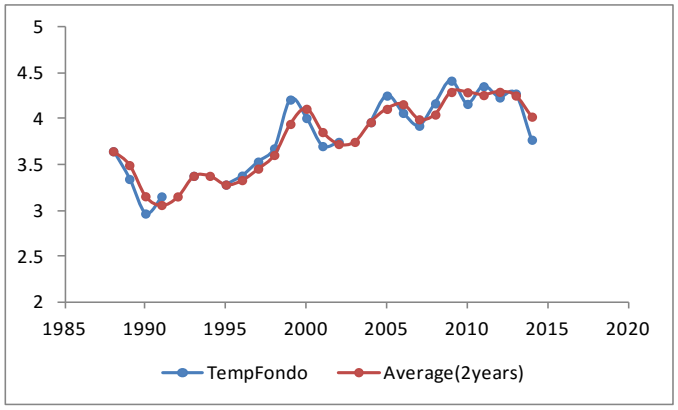


Figure 1. Average bottom temperature in the Flemish Cap, estimated from the CTD casts performed during the EU July bottom trawl survey. In blue color the average annual temperature is presented, while in red color, the average temperature from year *y* and year *y*-1 is shown.

The growth rate parameter K by age was estimated for ages 1 to 7. Estimation of this parameter for ages 8 and older was not possible due to the lack of sampled individuals in several years. The annual growth rate showed an increasing trend from 1995 to 2005 and a decreasing trend from 2005 to 2012 for all ages (Figure 2). However, from 1989 to 1995 the pattern was varied depending on the age, with an increasing trend for ages 1 and 2, while for all the remaining ages (except age 7) presented an slight increase followed by a steep decline from 1992/1993 to 1995/1996.

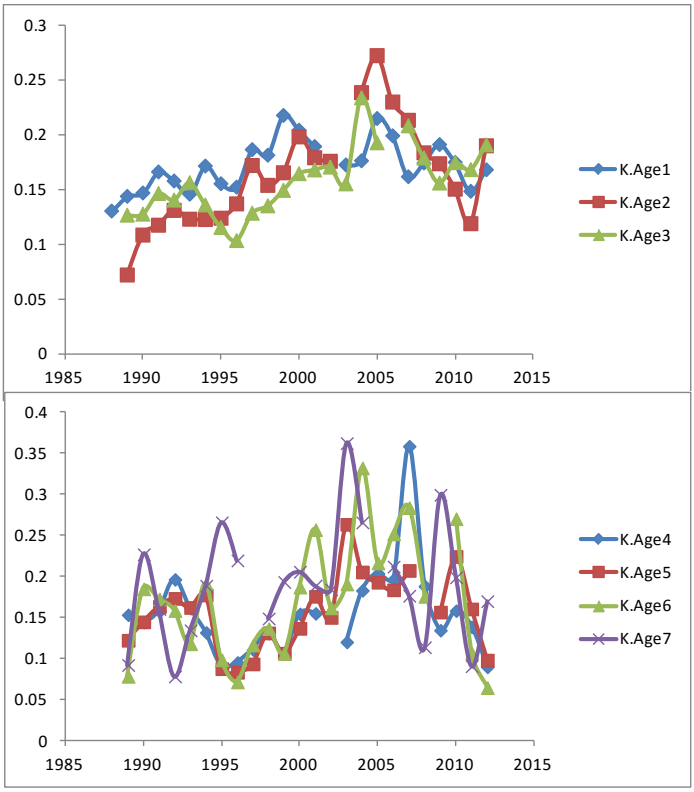


Figure 2. Annual growth rate K obtained for ages 1 to 7 using the von Bertalanffy growth function. Upper panel shows the value of K for ages 1 to 3, while the lower panel shows K values for ages 4 to 7.

The indexes of food availability for small cod (<60 cm) was mostly comprised by Hyperiids and Northern shrimp (Figure 3), which after a stable period from 1993 to 2003 showed a marked decline until 2012. For large cod (>60 cm), the food availability index was mostly influenced by the prey availability of redfish, wolfish and shrimp, and showed maximum values in 1995–1998 and 2006, followed by a sharp decline until 2011 (Figure 3).

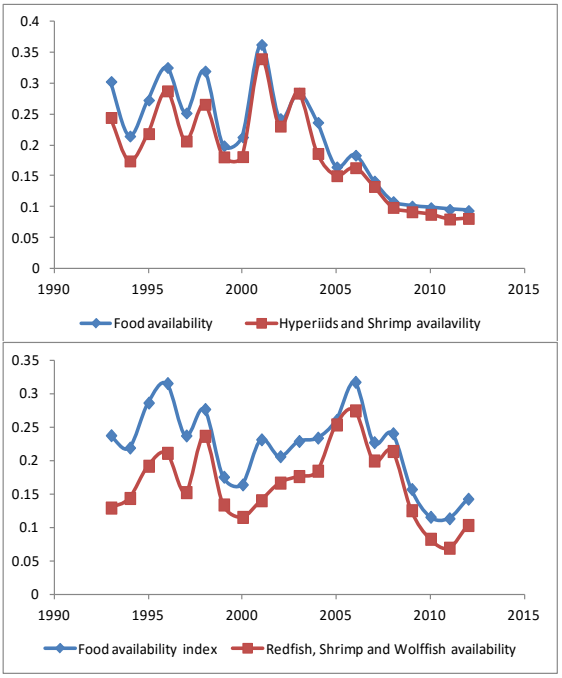


Figure 3. Index of food availability for small (upper panel) and large cod (bottom panel). Index of food availability (blue lines) and main prey availability (red lines) are shown.

As a preliminary approach it was assumed a linear relationship of the annual growth rate by age with food availability and water temperature, a linear regression was conducted. The food availability index did not show a significant linear effect on growth rate for any age (Figure 4). The water temperature showed a better fit to growth rates for ages 2, 3 and 6 (Figure 5). However, the fit was significantly improved when both water temperature and food availability were considered in the model (Figure 6). These results suggest that despite the simplification of assuming a linear relation in between the explanatory and response variables, during the last two decades, in the Flemish Cap, water temperature has been important for growth rate at early ages, but it is the interaction with food availability which explain most of the variation observed in the average annual growth rate by age.

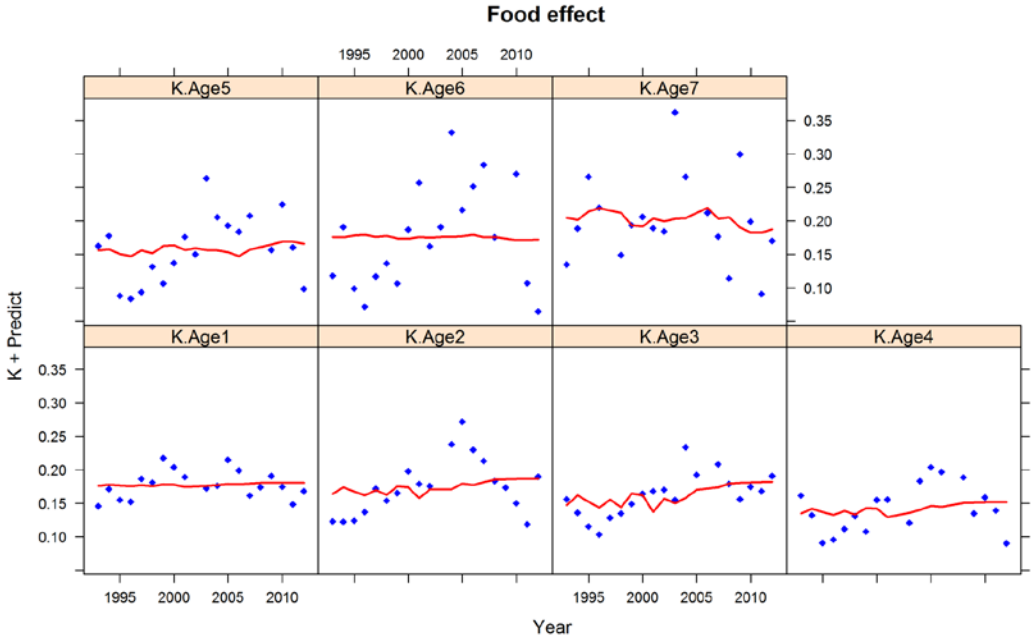


Figure 4. Estimated growth rate parameter K (blue points) and predicted value (red line) for each age and year when only the food availability index was included in the model.

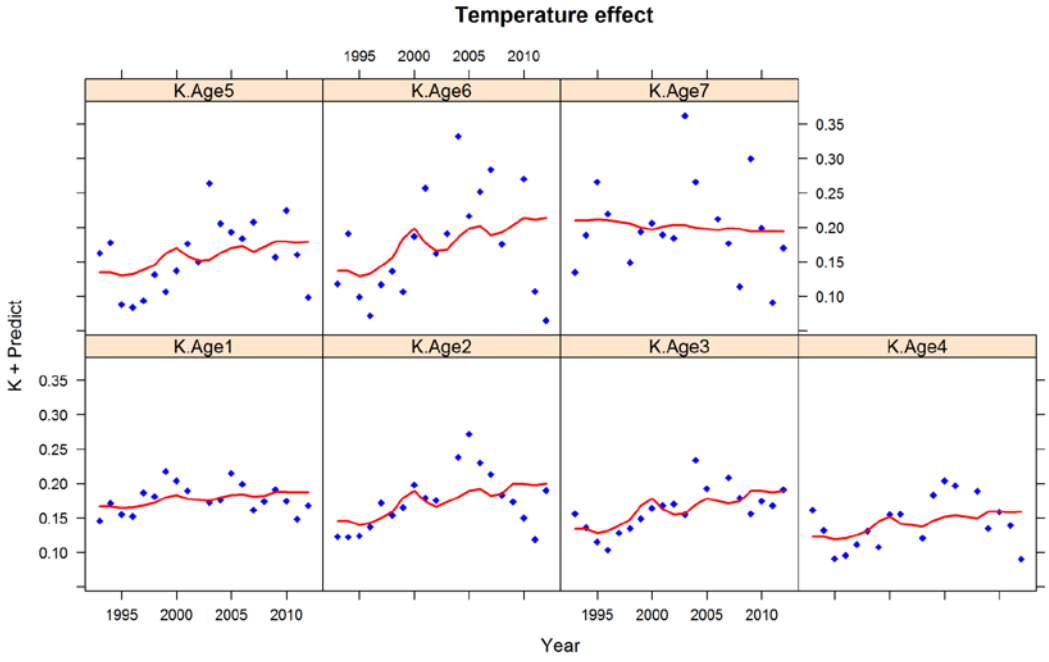


Figure 5. Estimated growth rate parameter K (blue points) and predicted value (red line) for each age and year when only the water temperature was included in the model.

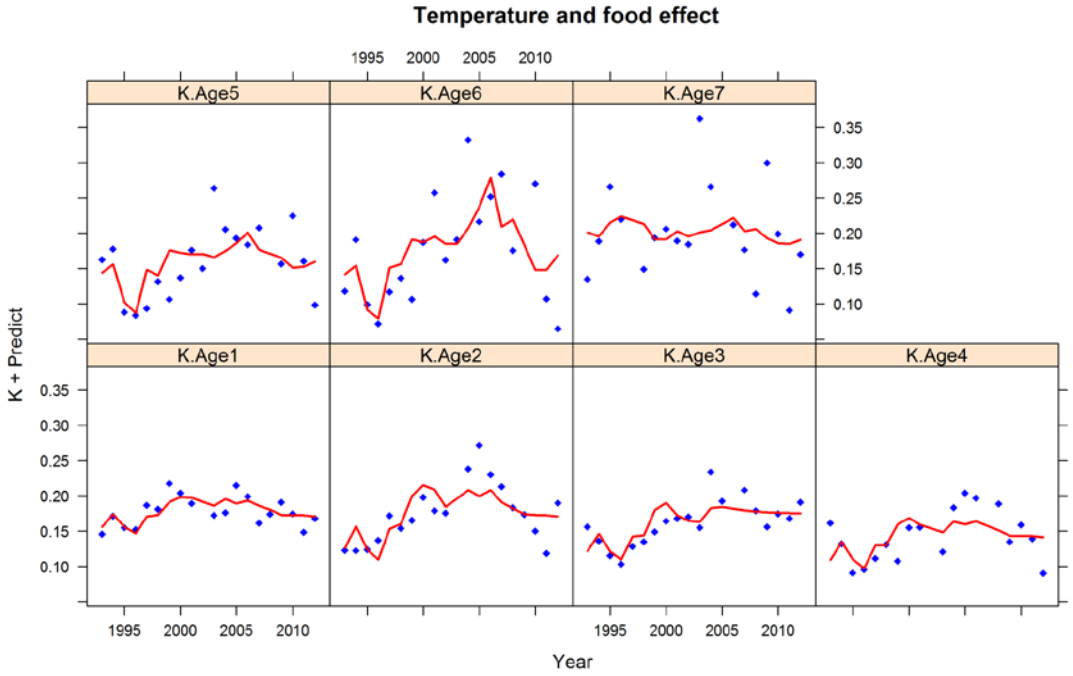


Figure 6. Estimated growth rate parameter K (blue points) and predicted value (red line) for each age and year when both water temperature and food availability index are included in the model.

Saithe environment-dependent growth

Xochitl Cormon[1], Bruno Ernande[1], Alexander Kempf[2], Youen Vermard[3] and Paul Marchal[1]

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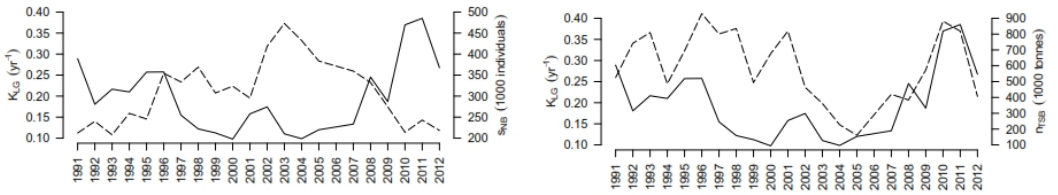
Saithe (*Pollachius virens*), the most landed demersal species in the North Sea, has seen its Spawning Stock Biomass decrease in the most recent years notwithstanding an exploitation at sustainable level (ICES, 2014). This recent decline follows a decrease of North Sea saithe mean weight-at-age (particularly for older ages) and might result, at least partially, from a decrease of saithe growth. Short-term growth changes may result from phenotypic plasticity due to changes in the environment. Particularly, a restriction of the food resource may result in a slower growth due to a lack of energy for the consumer (or a greater energy expense to access it). Food availability may change depending on different factors: (i) increased intra- or interspecific competition, (ii) abiotic environment changes, *i.e.* temperature, and (iii) fisheries. In this context, this study focused on saithe growth in relation to 3 environmental processes potentially involved: density-dependence, *i.e.* saithe abundance, main prey availability, *i.e.* Norway pout biomass, and sea surface temperature.

Saithe growth was characterized by its annual mean weight-at-age increment and by its annual growth coefficient estimated using the age-length key data available in DATRAS (1991–2012), non-linear regressions, and the logistic growth function:

$$l_a = l_\infty \times \frac{1}{(1+e^{-K_{LG} \times (a-a_i)})}.$$

The potential relation between annual saithe growth and the environment of the year before were explored using regressive techniques allowing the inclusion of temporal autocorrelation, i.e. General Least-Squares.

The mean weight-at-age increments presented too much interannual variability to be a good descriptor of saithe growth. The study of short-term environmental effects on K_{LG} revealed a significant negative effect of density-dependence (saithe abundance, Figure 1a) as well as a significant positive effect of main prey availability (Norway pout biomass, Figure 1b).



a) b)

Figure 1. Growth coefficient K_{LG} (solid line) and environmental factors (dashed line).

a) Density dependence . b) Main prey availability.

The results obtained allowed us to assume that Norway pout may be a limiting factors of North Sea saithe growth even if other preys must be important as density-dependence is also significant. In addition, these results allowed the inclusion of saithe growth and Norway pout biomass correlation in the multispecies stock assessment model SMS to study the impact of hake as a potential competitor of North Sea saithe.

Discussion

It was felt that this was an important area of work, and part of the process of bringing simulation and MICE models closer. However, the challenges involved are non-trivial, and progress is likely to be gradual.

Bayesian approaches were suggested as a method to combine different sources and qualities of information, which may be helpful given the scarcity of high quality data. It is obviously advantageous to produce fully mechanistic models, but tuning such models to the empirical field data across the whole system may well not be realistic. Bayesian approaches offer the benefit of incorporating previous results from studies of bioenergetics and aquaculture. Additionally, allometric scaling rules from physiology could be brought into a Bayesian framework to define prior distributions for quantities such as consumption-at-age.

It was noted that simply because the models produced a good hindcast behavior, this does not automatically imply good predictive power. This obviously applies for regression based approaches, where projecting beyond the data can cause the regression to cease to apply. However, a mechanistic model may have similar problems. There are often several parameters which trade off against each other, and a combination that can perform well under one set of environmental conditions may not do so under different conditions. This is the case with existing fisheries models, where for example natural mortality, recruitment and growth can trade off to give similar stock trends from different underlying parameterizations. When projected under different conditions the performance of the different combinations may well diverge. Although we probably have an intuitive understanding of what is likely to occur in the existing models, it is not obvious where all of the potential confounding might occur as we move to modelling prey-dependent growth. Two potential areas for confounding include 1) Consumption and assimilation, and 2) Maximum consumption rate and predator/prey overlap. These are instances where due to the confounding, mis-specified parameters may allow reasonable fits to historical data (biomass time-series), but models may give erroneous predictions under future conditions (i.e. under climate change) or scenarios (i.e. more balanced fishing, (Zhou *et al.* 2010; Garcia *et al.* 2012).

One key question was if one should use abundance indices of prey, or the ratio of predator to prey (which in practice equates to using a density dependent term). It was felt that there was increasing evidence that the ratio giving available food per kg of predator was superior. If a correlation is to be used as a basis of modelling growth, then it is important to regularly check that the correlation continues to hold.

There are a number of non-linearities involved in modelling growth in this way, which may be extremely difficult to resolve given the available empirical data. Prey switching is one such complicating factor. It is likely to be important in modelling the development of the prey stocks, in particular providing protection from excessive predation during simulations with periods of low prey stock biomass. It may also be the case that the degree to which predators can switch to other food sources has implications for how well they could tackle periods of shortages of their main prey species. Whether this is critical needs to be evaluated, probably on a per predator basis. The issue of spatial overlap is related to this, predator and prey distributions throughout the year may be critical for determining the feeding success of the predator, but are not well resolved in period survey data.

One potential issue is the energy content of prey, and especially the quality of that prey. Models which work in biomass will miss some of the consequences of switching to lower quality prey. Simply working in energy content does not solve this, as the model could allow the predator to eat an unrealistically large quantity of food in order to maintain the energy input. If poor quality food is being used (perhaps as a food of last resort) then the models would need adapting to deal with this.

Finally, the bioenergetics literature (Jobling 1995; Hanson *et al.* 1997) suggests that temperature effects on growth are likely to be substantial, as supported by the presentation on halibut growth by Kirstin Holsman (Holsman *et al.* 2015). However, there are other cases where empirical results suggest that prey density rather than temperature may drive predator growth (presentation by Xochitl Cormon and Alex Kempf).

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Annex 6: Report on Key Run for the North Sea Ecopath with Ecosim Ecosystem Model, 1991–2013

Key run summary sheet

Area	North Sea
Model name	Ecopath with Ecosim
Type of model	Food web compartment
Run year	2015
Species/ Groups	69 functional groups
Time range	1991–2013
Timestep	Monthly
Area structure	North Sea ICES division IVa,b,c
Stomach data	1991 year of the stomach and others
Purpose of key run	Calibration of model time dynamics, estimation of mortalitity rates, ecosystem indices and MSY rates.
Model changes since last key run	Second key run – addition of 1 seabrid group, extension of the time-series & routines for updating the model data.
Output available at	http://www.ices.dk/community/groups/Pages/WGSAM.aspx (see File Inventory section 6)
Further details in	Contact: clement.garcia@cefas.co.uk; chris.lynam@cefas.co.uk; steve.mackinson@cefas.co.uk

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About this report

This report describes the updates and parameterisation of the second Key Run of the North Sea Ecopath with Ecosim model and its calibration to time-series data 1991–2013. The contents have been presented and reviewed at the ICES WG Multispecies Assessment Model in November 2015. This Annex documents the specification and results of the key run. The report and output data files are made available *via* the WGSAM webpage. Additional information listed in the file inventory (Section 6) can be requested from the authors. The authors worked together through all stages of the modelling and reporting of this key run, with CG leading preparation of the data, development of all the

data handing and presentation routines, SM on the approach to model balancing, fitting and reporting, CL on methods for time-series weighting and modification of fleet catch profiles.

1. Quality assurance for operational multi-species models

It is likely that as the ICES community moves towards integrated ecosystem assessments the number of modelling tools and the number of regions in which they are used will increase. WGSAM (2013) proposed a review/quality assurance procedure for guiding which new multi-species models might be appropriate for 'acceptance' into the ICES advice giving process. The proposed procedure builds on the existing procedure for accepting Key Runs for a particular ecosystem, identifying 3 important reviewing/ quality assurance tasks as part of the procedure.

Peer review and documentation

Any modelling tool that is to be introduced for giving input into the advice giving process should go (or have been) through a peer review process. A precondition of this is that full documentation is made freely and easily available. The review could be in the form of one or more peer-reviewed papers describing the model, or through a dedicated review. This would assess the modelling tool in general, and give confidence that it performs in the manner described in the documentation.

Suitability

The peer review described above gives confidence that the modelling tool performs as intended. It is then important to evaluate whether the modelling tool as suitable for providing part of a multi-species advice giving process. This could take the form of a review at the annual ICES WGSAM meeting. Both the documentation and the peer review described in step 1 would need to be available prior to this evaluation being undertaken. In addition, model outputs should be available to test the model performance in a realistic setting. This could be in the form of fits to historical data, a self test of fitting to 'data' output from the model, and/or in the form of fitting to other 'known' datasets. It is also recommended that the model authors create a summary sheet describing the model (an extended version of those proposed by WKADSAM 2010), as described in Section 9 and Annex 5 of WGSAM 2013. Outputs from this evaluation would include a general assessment of the suitability of the modelling tool, and an overview of the strengths and weaknesses for different applications.

Performance – Key Runs

WGSAM suggests that there is a distinction to be made between accepting a modelling tool (e.g. SMS) as suitable for giving possible advice (or inputs to advice) and accepting the model implementation for a particular set of stocks in a given region (e.g. the SMS North Sea model). The acceptance of a particular implementations falls within the scope of the periodic review and publication of Key Runs which WGSAM already conducts for the North Sea and Baltic Sea.

A Key Run refers to a model parameterization and output that is agreed and accepted as a standard by ICES WGSAM, and thus serves as a quality assured source for scientific input to ICES advice. The process of accepting a Key Run involves presentation of the 'draft' Key Run in plenary, followed by nominated experts engaging with the modelling expert(s) to review the specification (inputs), outputs and documentation of the Key Run. Any required changes are agreed in plenary and documented. When completed, the nominated experts review the changes, and when satisfactory, the Key Run is published in the working group report and output data made available *via* the ICES website.

Prime purposes of a Key Run include:

a) Demonstrating the utility of a particular model formulation in a particular ecosystem and thereby building confidence that this formulation is appropriate to use in providing advice.

b) Providing consistent outputs relevant for use in assessment working groups and other ICES WGs (e.g. on food-web indicators and trends in biodiversity)

c) Assisting with the development of multi-model ensemble evaluation approaches by providing a 'standard' set up to aid understanding of different model frameworks, and a worked example of the results that can potentially emerge.

d) Contributing specific results for use in multi-model ensemble evaluations of fishing strategies.

Key Runs are typically run every three years, or alternatively, when a substantive change is made to the model parameters, when sufficient new data becomes available, or when the previous Key Run is deemed out of date (WGSAM 2013).

***[Note:** It should also be noted that nothing in this overall procedure extends to reviewing the code of the model directly, rather the stated algorithms governing the model and the model performance on the test datasets are the criteria on which acceptance would be based.]*

1.1. Update of the EwE North Sea Key Run

An EwE-NS Key Run refers to a model whose temporal dynamics (Ecosim predictions) are fitted to time-series of observation data, provides credibile predictions of sustainable fishing rates and shows good stability in long term equilibrium predictions. Key runs are sometimes referred to as a calibrated model. The procedure involves using historical data concerning fishing and environmental forcing functions affecting primary production & trophic rates, to drive model predictions of changes in ecosystem components and catch from fisheries.

Beyond the important objective to update the EwE-NS Key Run with new elements (e.g. time-series extended, more detailed ecological ecological data, improved species relationships understanding), this report also aims to present a quick and easy way to routinely update the Key Run when it is needed.

We therefore focus primarily on the 'easy-to-obtain' fisheries survey and assessment datasets (e.g. ICES data) and environmental factors known to have a strong impact on functional groups (e.g. sea temperature). We have aimed to avoid dependence on data owned by a specific institute or person. We have learnt by experience that some of these may be extremely time consuming to obtain and further, changes in ownership can ren-

der data availability variable from a year to another. To reduce any discrepencies due to variations in data quality and/or accessibility, we aim for this EwE-NS Key Run and its future versions to depend principally on data for which we are reasonably confident that they will remain equally accessible in the future.

No exploratory or fundamental ecological analysis is undertaken in the scope of this report. Only the building of the model, its calibration and the main output of the Key Run. The output files are made available on the WGSAM webpage and any additional information can be obtained by contacting the authors.

1.2. Steps of the update routine

After updating the base of the EwE model (i.e. Ecopath) (section 2), the report presents the data sources, the data handling routine and the final time-series outputs (section 3) that were used in calibration of the temporal dynamics (1991–2013) predicted by Ecosim (section 4). Section 5 presents the outputs of the Key Run.

2. North Sea Ecopath model

2.1. Updated model [file: NSea 2015 KEY RUN Snapshot.xlsx]

The North Sea Ecopath model originally published by Mackinson and Daskalov (2007) and first published as a Key Run in 2011 (ICES WGSAM 2011, and Mackinson 2014) was updated with:

- New fish data
- Two groups of seabirds
- Recent shrimp data
- Catch compositions of fleets
- Specification of multi-stanza parameters

An overview of the parameters updated from the 2011 Key Run is given in Table 2.1.

Table 2.1 Basic estimates of the Ecopath model used for the 2015 Key Run. Where changes were made the previous key run values are given in brackets. Where there is no specific comment, parameter changes were modeified during re-balancing the model, but keeping with the ranges given in the original technical report (Mackinson and Daskalov 2007). Details of rebalancing the ecopath model were documented (Appendix 2 - Ecopath Balancing.docx, available on request).

	Group name	Biomass	P/B	Q/B	EE	Comments
1	Baleen whales	0.067	0.02	9.9	0.00	
2	Toothed whales	0.017	0.02	17.63	0.00	
3	Seals	0.008	0.09	26.8	0.00	
4	Surface-feeding sea-birds	0.002 (0.003)	0.237 (0.28)	77.28 (216)	0.00	Seabird split in two groups and reassessed with NS estimates (Staebler pers comm) and Celtic Sea (Lauria 2013)
5	Juvenile sharks	0.001	0.5	2.5	0.19	
6	Spurdog	0.13	0.48 (0.6)	2	0.23	Biomass value assuming that the proportion of the NEA stock in the NS is equivalent to the ICES reported catches
7	Large piscivorous sharks	0.001 (0.002)	0.44 (0.48)	1.6	0.62	
8	Small sharks	0.002	0.51	2.96	0.34	
9	Juvenile rays	0.268	0.66	1.7	0.01	
10	Starry ray + others	0.39 (0.109)	0.66	1.7	0.05	Fraser *et al.* (2007), 1998 estimate (0.53 t/km2) scaled back to 1991 using IBTS Q1 time-series
11	Thornback & Spotted ray	0.066	0.78	2.3	0.22	
12	Skate + cuckoo ray	0.05	0.35	1.8	0.39	
	Cod					
13	Cod (juvenile 0–2)	0.101 (0.124)	1.79	4.96 (8.01)	0.99	Update of adult-juvenile life-history parameters
14	Cod (adult)	0.13 (0.161)	1.19	2.17 (3.5)	0.91	Consistency with new assessment values for B and F
	Whiting					
15	Whiting (juvenile 0–1)	0.026 (0.021)	2.36	17.4	0.92	Update of adult-juvenile life-history parameters
16	Whiting (adult)	0.43 (0.35)	0.89	5.46	0.98	Consistency with new assessment values for B and F
	Haddock					

	Group name	Biomass	P/B	Q/B	EE	Comments
17	Haddock (juvenile 0–1)	0.0077 (0.0066)	2	7.68 (14.38)	0.88	Update of adult-juvenile life-history parameters
18	Haddock (adult)	0.12 (0.104)	1.14	2.35	0.82	Consistency with new assessment values for B and F
	Saithe					
19	Saithe (juvenile 0–3)	0.116 (0.139)	1	8.51 (8.28)	0.90	Update of adult-juvenile life-history parameters
20	Saithe (adult)	0.21 (0.22)	0.88 (0.95)	3.6	0.72	Consistency with new assessment values for B and F
21	Hake	0.014	0.82	2.2	0.68	
22	Blue whiting	0.23 (0.08)	2.5	9.06	0.32	New estimation of biomass from Single species assessment corrected with landings proportion
23	Norway pout	1.31 (1.39)	2.2	5.05	0.98	
24	Other gadoids (large)	.	1 (1.27)	2.5 (3.2)	0.95	
25	Other gadoids (small)	.	1.8 (2.3)	4 (6)	0.99	
26	Monkfish	0.042	0.7	1.7 (1.9)	0.85	
27	Gurnards	0.18 (0.077)	0.82	3.2	0.26	Fraser *et al.* (2007), 1998 estimates (0.33 t/km2), scaled back to 1991 using IBTS Q1 time-series
	Herring					
28	Herring (juvenile 0–1)	0.143 (0.085)	1.31	11.5 (12.5)	0.89	Update of adult-juvenile life-history parameters
29	Herring (adult)	2.68 (1.96)	0.8	4.34	0.57	Consistency with new assessment values for B and F
30	Sprat	0.579	2.28	5.28 (6)	0.84	
31	Mackerel	0.75 (1.72)	0.6	1.73	0.75	New estimation of biomass from SMS 2014
32	Horse mackerel	0.75 (0.58)	0.9 (1.2)	3.5	0.23	New estimation of biomass from SMS 2014
33	Sandeels	1.85 (3.12)	2.28	5.24 (10.1)	0.99	Consistency with new assessment values for B and F
34	Plaice	0.58 (0.703)	0.85	3.42	0.85	Consistency with new assessment values for B and F
35	Dab	2.8 (3)	0.672	4 (3.36)	0.22	Sparholt (1990)
36	Long-rough dab	0.35	0.7	4 (3.4)	0.49	
37	Flounder	0.25	1.1	3.2	0.26	
38	Sole	0.135 (0.158)	0.8	3.1	0.88	Consistency with new assess-

	Group name	Biomass	P/B	Q/B	EE	Comments
						ment values for B and F
39	Lemon sole	0.14 (0.305)	0.864	4.32	0.50	
40	Witch	0.082	0.9	3	0.40	
41	Turbot	0.027 (0.054)	0.86	2.1 (2.3)	0.58	Consistency with new assessment values for B and F
42	Megrim	0.034	0.72	3.1	0.25	
43	Halibut	0.033	0.16	3.14	0.28	
44	Dragonets	0.045	1.44 (1.5)	6.9 (6)	0.96	
45	Catfish (Wolffish)	0.014	0.48	1.7	0.80	
46	Large demersal fish	.	0.55	2.54	0.90	
47	Small demersal fish	.	1.42	3.7	0.99	
48	Miscellaneous filterfeeding pelagic fish		4	10.19		0.99
49	Squid & cuttlefish	0.06 (0.08)	4.5	15 (20)	0.99	
50	Fish larvae	.	4	20	0.99	
51	Carnivorous zooplankton	.	4	.	0.99	
52	Herbivorous & Omnivorous zooplankton (copepods)	16	9.2	30	0.38	
53	Gelatinous zooplankton	0.066	2.9	.	0.79	
54	Large crabs	1.2 (1.35)	0.55	.	0.99	
55	Nephrops	0.98 (1.1)	0.37	.	0.99	Consistency with new assessment values
56	Epifaunal macrobenthos (mobile grazers)	78	0.38	.	0.43	
57	Infaunal macrobenthos	136	1	.	0.27	
58	Shrimp	0.074	11 (3)	22	1.00	Recent estimates for Crangon (WGCRAN 2013, Temming & Hufnagl 2012 & Staebler pers comm. And for Pandalus (WGPAN 2013)
59	Small mobile	30	1.36 (1.9)	.	0.98	

	Group name	Biomass	P/B	Q/B	EE	Comments
	epifauna (swarming crustaceans)					
60	Small infauna (polychaetes)	150	0.9	.	0.87	
61	Sessile epifauna	105	0.26	.	0.03	
62	Meiofauna	.	35	125	0.99	
63	Benthic microflora (incl Bacteria protozoa))	0.105	9470	.	0.95	
64	Planktonic microflora (incl Bacteria protozoa)	1.44 (1.46)	571	.	0.73	
65	Diving seabirds	0.004	0.45	86.97	0.00	Seabird split in two groups and reassessed with NS estimates (Staebler pers comm) and Celtic Sea (Lauria 2013)
66	Phytoplankton	7.5	286	.	0.21	
67	Detritus - DOM -water column	25	.	.	0.91	
68	Detritus - POM - sediment	25	.	.	0.94	
69	Discards	1.00E-06	.	.	0.99	

2.1.1. Update of fish data

Recent (2014) ICES assessments, were used to update the biomass, catches and fishing mortality rates for cod, haddock, whiting, saithe, blue whiting, Norway pout, herring, sandeels, plaice and turbot. Biomass estimates of several non-assessed fish functional groups (spurdog, dab, lemon sole, gurnard, starry ray) were also re-examined in light of new data based on survey and model estimates. See Table 2.1.

Horse mackerel (Trachurus trachurus) and mackerel (Scomber scombrus)

Estimates of biomass from the SMS Key Run 2014 were used to update biomass estimates for horse mackerel and mackerel, both of which represent the North Sea stock and North Sea components of the North East Atlantic (NEA) stock (WGWIDE 2014). For mackerel, the North Sea component of NEA stock is 2.86% (123 952 t), and the resulting total biomass estimate (427 000 t). For horse mackerel, the North Sea component of NEA stock is 6.79% (273 600 t), giving a biomass estimate of 427 784 t. This is higher than the value

used in the previous EwE key run, which used Ruekert *et al.* (2002) estimate of the North Sea stock of 96 160 t.

Estimate of Z for horse mackerel

Currently, there is no agreed assessment for horse mackerel in the North Sea. The latest assessment (ICES WKHOOMP 2014) assumed M for western horse mackerel (the main component in the North Sea) to be 0.15 across all ages, and F approx. 0.43, giving an estimate of Z= 0.58 which is used in the model.

Blue whiting (*Micromesistius poutassou*)

Blue whiting biomass is estimated to be approximately 346 000t (0.6 t/km2), based on assuming that the proportion of the NEA stock in the North Sea is equivalent to the proportion of the catches taken in the North Sea. However, the estimate of 0.6 provides an F inconsistent with the F from times series (0.27). This inconsistency would cause problems in Ecosim dynamics when fitting to the assessment data, so instead biomass is set to 0.23 t/km2, to give an F comparable with the time-series.

Spurdog (*Squalus spp*)

Spurdog biomass is estimated to be approximately 73 000t, (0.13 t/km2), based on assuming that the proportion of the NEA stock in the North Sea is equivalent to the proportion of the ICES reported catches taken in the North Sea (21% average 1991–2012).

Dab (*Limanda limanda*)

Sparholt (1990) estimated the biomass of dab to be approximately 1.6 millions tonnes (2.8t/km^2).

Starry Ray (*Raja spp*)

Fraser *et al.* (2007) estimates from 1998 scaled back to 1991 using IBTS Q1 gave a total biomass for Starry Ray of 222 300t (0.39t/km^2).

Gurnards (*Chelidonichthys cuculus*)

In light of new data, the biomass of gurnard in the previous model was considered to be too low (43 900t). Fraser *et al.* (2007) estimate of 190 000t (0.33t/km^2) in 1998, which was scaled back to 1991 using IBTS Q1 time-series to give 0.18t/km^2. Other estimations included IBTS CPUE by length (where CPUE index is scaled to an average biomass over the time-series) – 205 000t (0.36t/km^2) - see WGSAM 2014, SMS 2014 KeyRun for 1991: 97 142t (0.17/km^2) and Sparholt (1990) – 100 000t (0.18t/km^2).

Juvenile herring (Clupea harengus)

The K parameter of herring multistanza was update from 0.38 to 0.42 based on more recent estimates for the North Sea (WGHAWG 2015).

2.1.2. Revision of seabirds functional groups

Seabirds were split in to two functional groups, with parameters updated based on recent, more detailed estimates from the North Sea (Staebler pers. Comm) and Celtic Sea (Lauria 2013).

Diving seabirds – includes species that dive for their food, foraging on zooplankton and small fish. These tend to be mostly small species but not only. It includes, e.g., northern gannet (*Morus bassanus*), common guillemot (*Uria aalge*) or razorbill (*Alca torda*)

Surface feeding seabirds – includes species whose diet includes a significant fraction of fish (and other fauna) discarded from fisheries. Principal species include, e.g., gulls (*Larus* spp), kittiwakes (*Rissa* spp), terns (*Lari* spp).

Biomass densities are based on assessments from ICES WGBIRD 2013 and ICES WGSE2013, and P/B and Q/B rates from Lauria's (2013) estimated values for the Celtic Sea.

2.1.3. Update of shrimp data

Recent estimates of *Crangon crangon* biomass and catches from WGCRAN2013 and Temming & Hufnagl (2014) were used to update the shrimp functional group. Biomass density in the southern North Sea was estimated to be 0.055 t/km² with catches for the year 1991 of 17 400 t giving an exploitation rate of 0.91. Using a *Pandalus borealis* catch value of 10,000 t (http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2014/2014/pandsknd.pdf) and assuming the same exploitation rate as *C. crangon*, *P. borealis* biomass density was estimated to be 0.018 t/km². Total shrimp biomass in Ecopath therefore becomes 0.074 t/km² and total catches 0.068 t/km². Discards of the shrimp group are estimated to be around 50% of catch bases on the estimates for *C. crangon* (Staebler pers com).

P/B for *C. crangon* is estimated to be in the range 9–13, with a value of 11 being used in the model. Maximum Q/B is estimated to be 25, with a value of 22 being used in the model.

2.1.4. Multi-stanza group parameters

Minor adjustments were made to the parameters of the multi-stanza groups as part of the calibration of time-series dynamics. See Table 4.4. in section 4.1.3.

2.1.5. Landings and discard profiles of the fisheries

Using the data in the STECF 2013 Effort database (STECF 2013), the landings and discard proportions of the 12 modelled fleets (Table 2.2) were modified to reflect the recent catch profiles of each fleet. Landing and discard data for 2011/2012 were summed across each model gear categories and North Sea subareas, then divided by 2 to get the average 2011/2012 values. For each of the multistanza groups, the percentage of landing and discards for juvenile groups was based on the percentage of discards for each age groups reported in reported in ICES WGNSSK 2014. (ref: supporting spreadsheet EwEDiscards.xls). The average catch for those groups caught by each fleet was then scaled up given the relative effort by fleet in 2011/2012 compared to 1991 levels. The total catch of each group following the application of the fleet-specific scaling factors, was then modi-

fied to match the total catch reported in 1991. This process of 'reverse engineering' the catch compositions of the fleets in the 1991 ecopath model ensures that model simulations reflect as close as possible the behaviour of the present day fleets in terms of their fishing mortality while the temporal fitting process aims to ensure the correct level of catch is attained throughout the time period modelled.

Table 2.2 Gear categories from STECF Effort database mapped to the model fleets

Gear	Main species caught by volume	% of total	EwE Fleet
Beam trawls	Crangon shrimp	>=90%	Shrimp trawl
Bottom otter trawls (multi rig and pair)	Sandeel, herring	>=90%	Industrial trawl
Demersal seines (fly shooting, anchored and pair)	Haddock, whiting, cod, mackerel, herring, plaice, dab, horse mackerel	>=90%	Demersal trawl & seine
Dredges	Scallop	>=90%	Dredges
Pelagic seines (purse, fly shooting and anchored)	Herring, mackerel, sprat	>=90%	Pelagic trawl & seine
Pelagic trawls (otter and pair)	Herring, mackerel, sprat, horse mackerel	>=90%	Pelagic trawl & seine
Pots and traps	Edible crab	>=90%	Pots
Regulated beam trawls >= 120 mm	Plaice, cod, lemon sole, dab	>=90%	Beam trawl
Regulated beam trawls >= 80 <120 mm	Plaice, sole, dab, cod	>=90%	Beam trawl
Regulated bottom otter trawls (multi rig and pair) >= 100 mm	Saithe, haddock, cod, plaice, whiting, anglers	>=90%	Demersal trawl & seine
Regulated bottom otter trawls (multi rig and pair) >= 16 <32 mm	Sprat, norway pout, blue whiting	>=90%	Industrial trawl
Regulated bottom otter trawls (multi rig and pair) >= 70 <100 mm	Nephrops, whiting, plaice, haddock, cod, mackerel	species not in brackets account for 80%	Nephrops trawl
Regulated gill nets	Cod, plaice, sole, anglers	84%	Drift and fixed nets
Regulated longline	Mackerel, hake, cod, conger, bass, spurdog, skates	>=90%	Gears using hooks
Regulated trammel nets	Sole, plaice	84%	Drift and fixed nets
Unknown	Cod, plaice, herring, sprat, sandeel, sardine	88%	Other

2.1.6. Fisheries economics and employment

No changes were made to economic data in the model, thus the cost and revenue of each modelled fleet, and the differences in catch value of each species to each fleet reflect data reported in the 2008 Annual Economic Report (EU 2008).

2.2. Updated Ecopath model outputs [file: NSea 2015 KEY RUN Snapshot.xlsx]

Key Output estimates representing a static snapshot of the North Sea ecosystem in 1991 are available in an excel spreadsheet upon request.

- Mortality rates - Predation and Fishery (partial F's)
- Consumption estimates
- Predator-prey interaction indices
- Ecosystem state indicators
    - Flow to detritus. (t/km²/year)
    - Net efficiency
    - Omnivory index
    - Summary system level statistics of regarding production, consumption, food-web connectivity and energy flows
    - Respiration indices
    - Energetic pathways and flows

3. Time-series data sources and treatment

3.1. Metadata summary [file: North Sea Time Serie 1991_2013_1Dec2015.csv]

Data on biology, fisheries and environmental variables covering the period 1991–2013 were collated and used for calibrating the biomass dynamics of the model. The aim of the data collation was to obtain quantitative information on as many functional groups as possible so that their modelled dynamics was subject to constraints justified by available data.

The data include stock assessment data, biological survey data, fishing mortalities, catch, fishing effort, and environmental data, resulting in a complete data set of 300 variables (Appendix 1, available on request), 116 of which are used in the key run presented here (see section 5). Table 3.1 and 4.1 summarise the data sources, with the details provided in the sections below.

First we introduce all the data at our disposal for the model fitting, then describe the data handling and processing, and finally state those used for each group during the model fitting.

Note:

Many of the information sources provide data for different regions. ICES is making great efforts to make its data assets publicly available via an online warehouse, so it is worth checking there frequently for updates. http://ecosystemdata.ices.dk/

Table 3.1. Metadata summary table. NOTE: Only data from 1991 onwards are used in the model calibration.

Data type	Dates (min to max)	Database/Model	Used for	Source	Dataset number
Catch	1991–2013	ICES Catch Statistics	Fitting catch / display	http://www.ices.dk/marine-data/Pages/default.aspx	I
Catch	1991–2013	SMS 2013 Key run	Fitting catch	(Rindorf,A. Vinther. M pers comm 3–12th April 2015). Also ICES WGSAM (online data)	II
Catch	1991–2014	Single species (SS) stock assessments	Fitting catch	ICES data online and WG reports http://standardgraphs.ices.dk/stockList.aspx	III
CPUE	1991–2013	Cephalopods	Fitting catch	Cephalopods (Graham Pierce, pers. comm.) & ICES WGCEPH 2014	IV
Relative biomass	1991–2008	IBTSQ1 survey	Fitting biomass	ICES datras	V
Relative biomass	1991–2014	Single species (SS) stock assessments	Fitting biomass	ICES data online and WG reports http://standardgraphs.ices.dk/stockList.aspx	VI
Relative biomass	1991–2013	SMS 2013 Key run	Fitting biomass	(Rindorf,A. Vinther. M pers comm 3–12th April 2015). Also ICES WGSAM (online data)	VII
Relative biomass	1991–2013	Continuous Plankton Recorder abundance and biomass	Fitting biomass	Licandro, Johns SAHFOS	VIII
Fishing mortality	1991–2014	Single species (SS) stock assessments	Driver	ICES data online and WG reports	IX

Data type	Dates (min to max)	Database/Model	Used for	Source	Dataset number
				http://standardgraphs.ices.dk/stockList.aspx	
Fishing mortality	1991–2013	SMS 2013 Key run	Driver	(Rindorf,A. Vinther. M pers comm 3–12th April 2015). Also ICES WGSAM (online data)	X
Total mortality	1991–2013	SMS 2013 Key run	Fitting mortality	(Rindorf,A. Vinther. M pers comm 3–12th April 2015). Also ICES WGSAM (online data)	XI
Relative biomass	1993–2006	National Maring Monitoring Programme - Benthos	Fitting biomass	Cefas Unicorn database	XII
Relative biomass	1984–2006	Thames and Northumberland time-series	Fitting biomass	Cefas Unicorn database	XIII
Fishing effort, by gear	1991–2012	STECF Effort data 2013	Driver	STECF effort database 2013, Online. Plus appended effort data from previous key run for year prior to 2000. https://stecf.jrc.ec.europa.eu/data-reports	XIV
Environ-NAO Winter Index	1991–2013	http://www.cgd.ucar.edu/cas/jhurrell/indices.html	Driver	Web	XV
Environ-AMO	1991–2013	http://www.esrl.noaa.gov/psd/data/timeseries/AMO/	Driver	Web	XVI
Environ-AMO smoothed (USGS)	1991–2009	http://www.esrl.noaa.gov/psd/data/timeseries/AMO/	Driver	Web	XVII

Data type	Dates (min to max)	Database/Model	Used for	Source	Dataset number
Environ-HADISST	1991–2013	North Sea Hadley Centre data from Rayner *et al.* 2003, as in MacKenzie and Schiedek 2007	Driver	Publication based on Hadley Centre data	XVIII

3.2. Relative biomass

Most relative biomass time-series were available up to 2013. In some cases they were only available up to 2012, so to complete the time-series we maintained the last value as a constant, under the weak, but not unreasonable assumption that the last years' value is the best predictor of the next year (i.e. strong autocorrelation in time-series).

3.2.1. Fish stock assessments

Single species stock assessment

ICES member states undertake numerical assessments of the status of stocks in the North Sea. A variety of models based on the principals of Virtual Population Analysis are used. Details of individual stock assessments are provided in ICES working group reports (WGNSSK in the case of the North Sea) and summarised by region in ICES advice. In 2009, the input and output files of ICES stock assessments for each region became available online for the first time and has been updated on a yearly basis, containing data on: Recruitment, Spawning stock biomass (SSB), Total Biomass, Landings, discards and Mean Fishing mortality. The latest version of the assessment (2014) was used for the present work.

Source

Data freely available from the following link: http://standardgraphs.ices.dk/stockList.aspx. Note that only assessed species parameters can be obtained from this dataset (see Figure 3.1 and Table 3.1). Selection is done by selecting the North Sea ecoregion of the latest year available (2014). Three species being assessed at a scale larger than the North Sea (i.e. over-dispersed species), mackerel, horse mackerel and blue whiting need to be found "manually" by entering only the latest year available. Data downloaded under .csv format.

Formatting

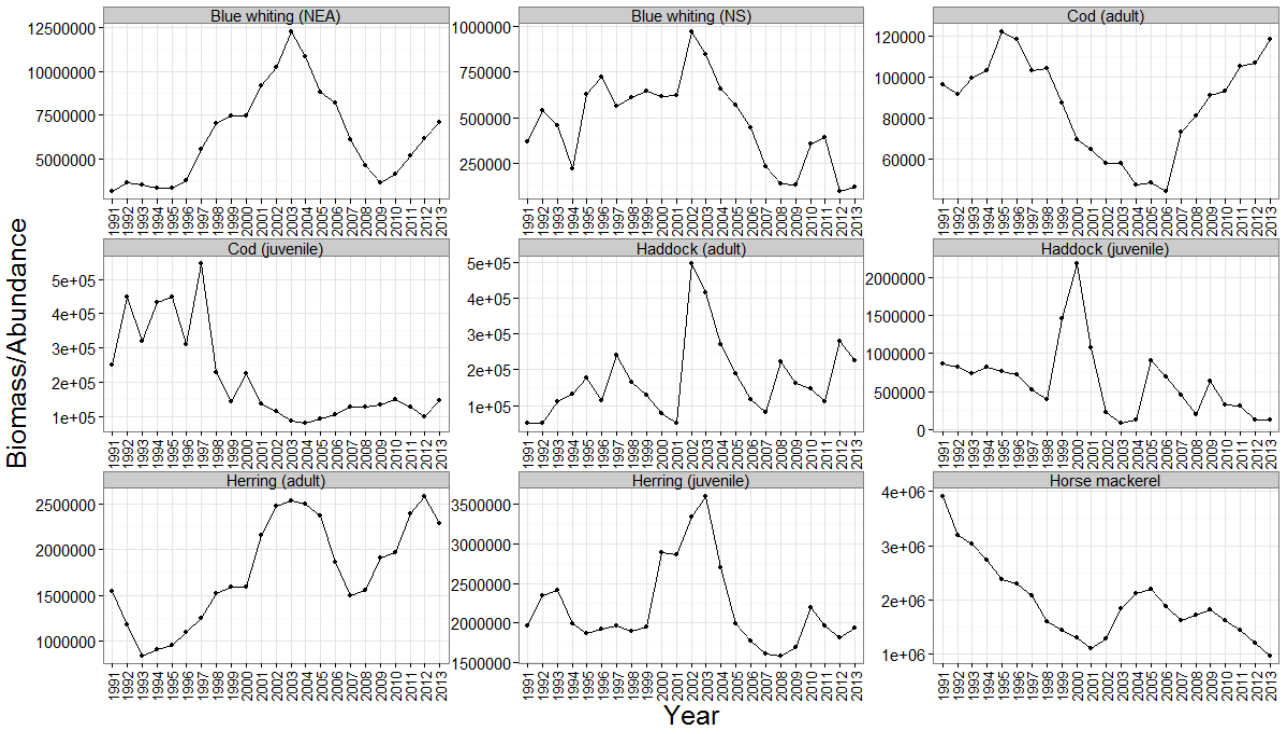
The data formatting is made using the free software R (R Core Team 2014) – script available on demand to C. Garcia); the parameter selected are SGName (assessed species), year, Tbiomass (total biomass), SSB (spawning stock biomass), catches, landings and F (Fishing mortality). Five species have been parameterised as multi-stanza in the model (cod, haddock, herring, saithe and whiting), for these, SSB values is removed from Tbiomass value to obtain juvenile and adult specific biomass. For the rest of the species, only Tbiomass is considered. Landings, catches and F are considered for the whole group and applied to the adult only for the five multi-stanza species.

Raw data parameters are readily available per species and per year therefore little formatting is needed, likewise no relation to functional group *via* the lookup table is necessary since the assessed species are represented "as they are" in the EwE Key Run. In the case of sandeel, the assessments cover separate stocks in the North Sea. In order to have one value per year only, biomass, catches and landings were summed while F was averaged.

Note that some species (e.g. nephrops, bird, seals, cephalopods) are not available under .csv format on the ICES website, for those, information have been transferred manually from the pdf copy of the latest advice and then treated as described as above wherever possible (see Figure 3.2 *(but nephrops included in Figure 3.1)*).

Export

Formatted data are then exported under a .csv format and present a value for each group and each year for biomass.



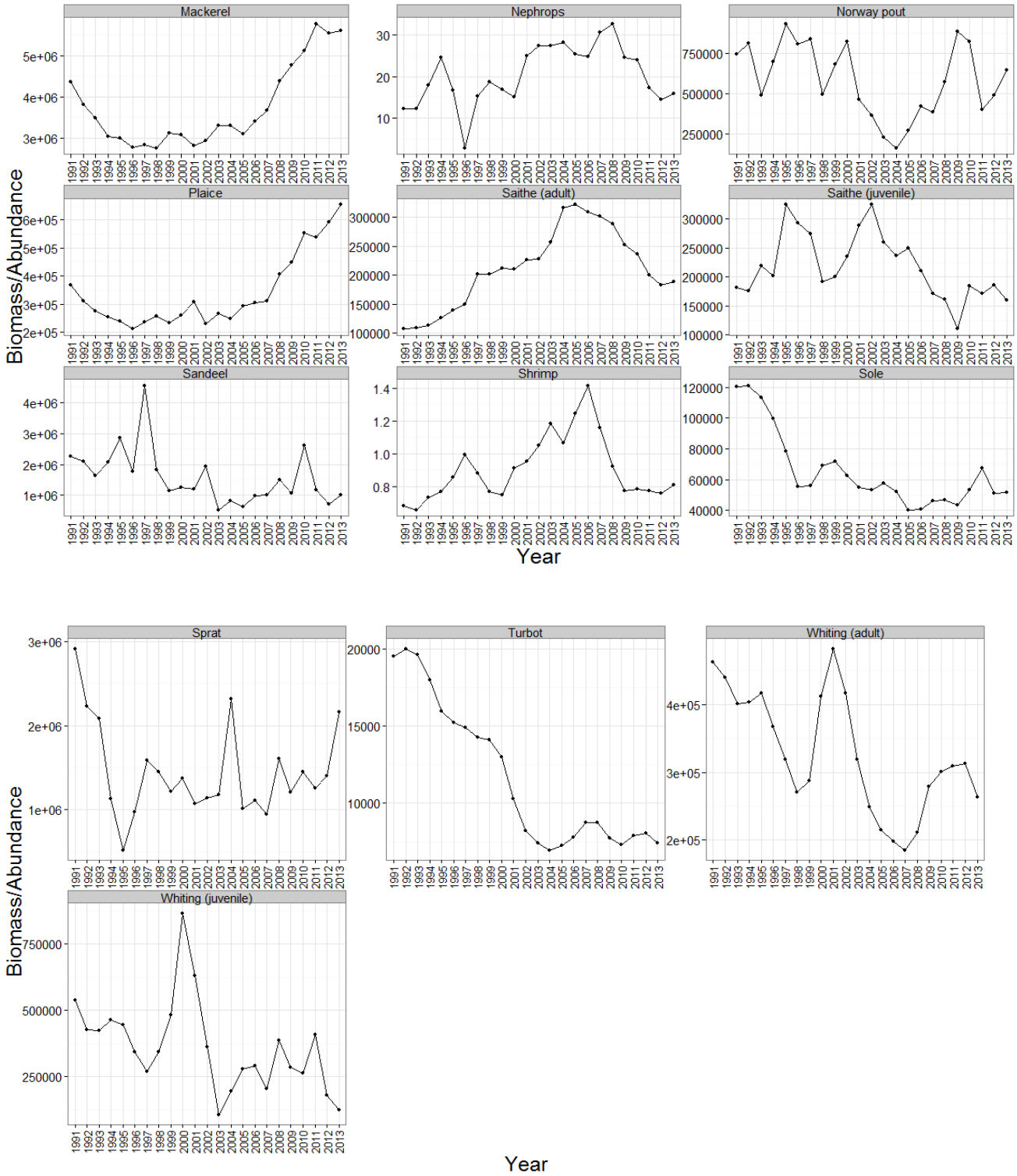


Figure 3.1. Biomass in tonnes of Wet Weight (WW) from the Single Species assessment data available to be used as relative biomass series in model fitting. NEA: North East Atlantic, NS: North Sea. Nephrops expressed in relative abundance and Shrimp expressed in biomass index.

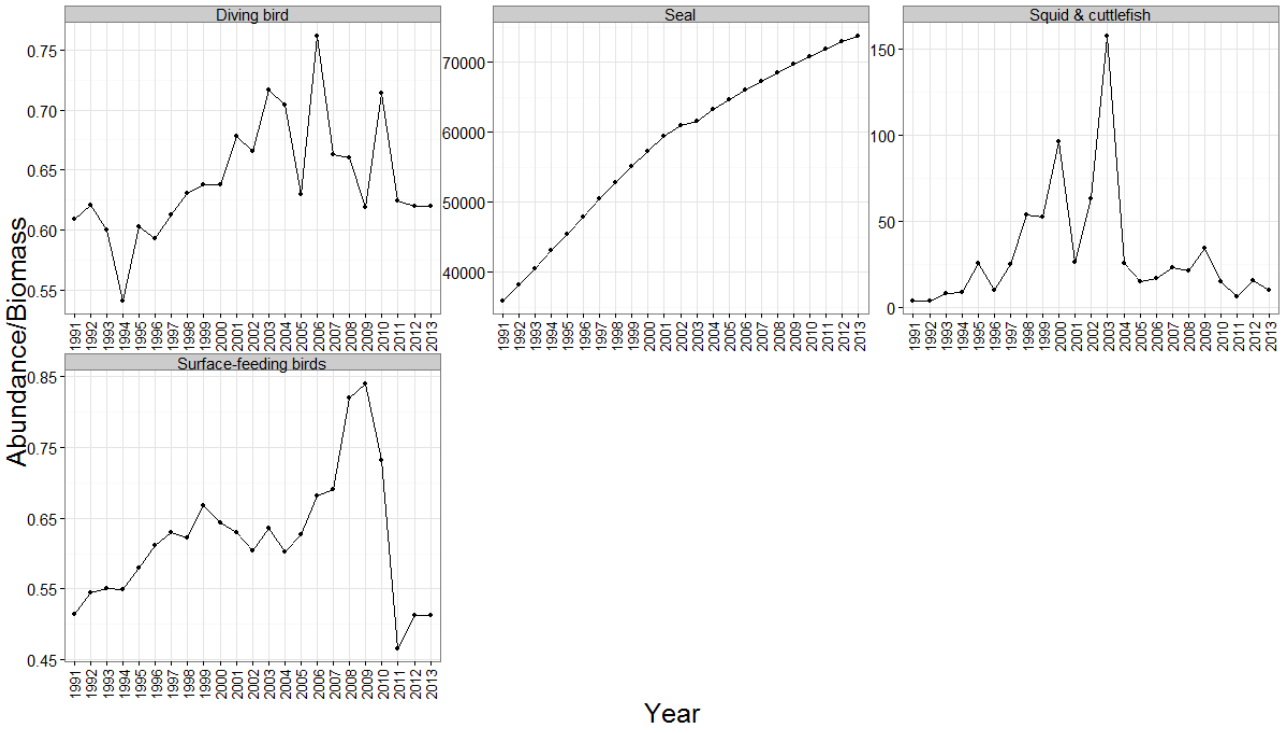


Figure 3.2. Abundance in relative proportion (diving and surface-feeding birds) and biomass in tonnes from the group-specific latest ICES advice report available to be used as relative biomass series to be used in model fitting.

Multispecies assessment SMS 2014 Key run

SMS (led by Vinther and Lewy at DTU-Aqua) is a multispecies model used in the ICES community to estimate the predation mortalities of 8 main predators in the North Sea. It is an extension of earlier models, 4M and MSVPA. ICES WGSAM publishes key runs in its working group reports. Time-series from the SMS Key run published in WGSAM 2014 were used in the model fitting.

http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=193

Source

Rindorf, A. Vinther. M pers comm 3–12th April 2015. Also online at ICES WGSAM

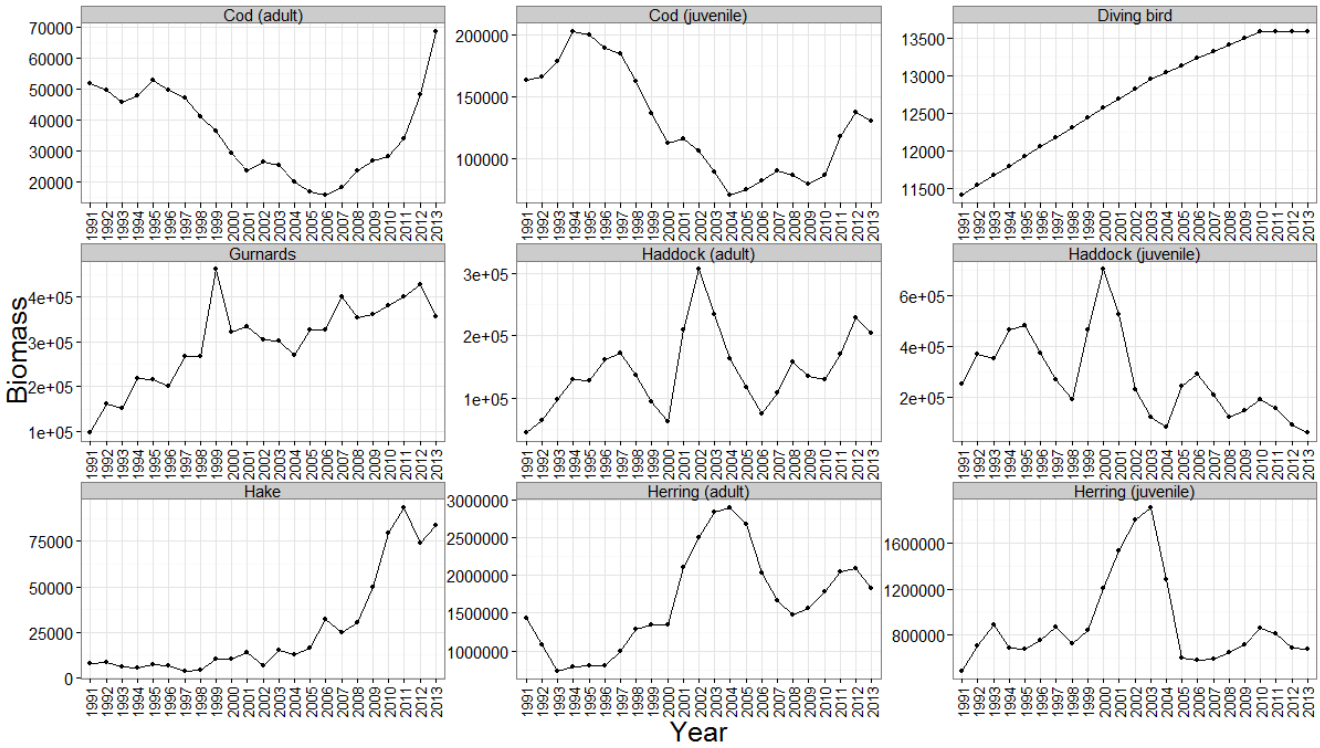
Formatting

Data formatting was done using the free statistical software R; the following parameters were selected: species, year, quarter, age, BIO (total biomass), SSB (spawning stock biomass), N (abundance), N.bar (average abundance), F (fishing mortality), Z (total mortality) and yield (catches). Similarly, the biomass of the five multi-stanza species were separated into juvenile and adult biomass. The other biomass values and parameters were calculated at the level of each species with no separation. To obtain one value per age and per year, biomass and catches are averaged across all quarters, while F and Z rates are summed across quarters. Then for biomass, abundance, average abundance and

catches the values were summed for all ages, for F and Z the values were averaged. Each species was then attributed to a functional group using a lookup table and similarly summed (biomass, abundance, average abundance and catches) or averaged (F and Z).

Export

Formatted data are then exported under a .csv format and present a value per functional group and per year for biomass (Figure 3.3)



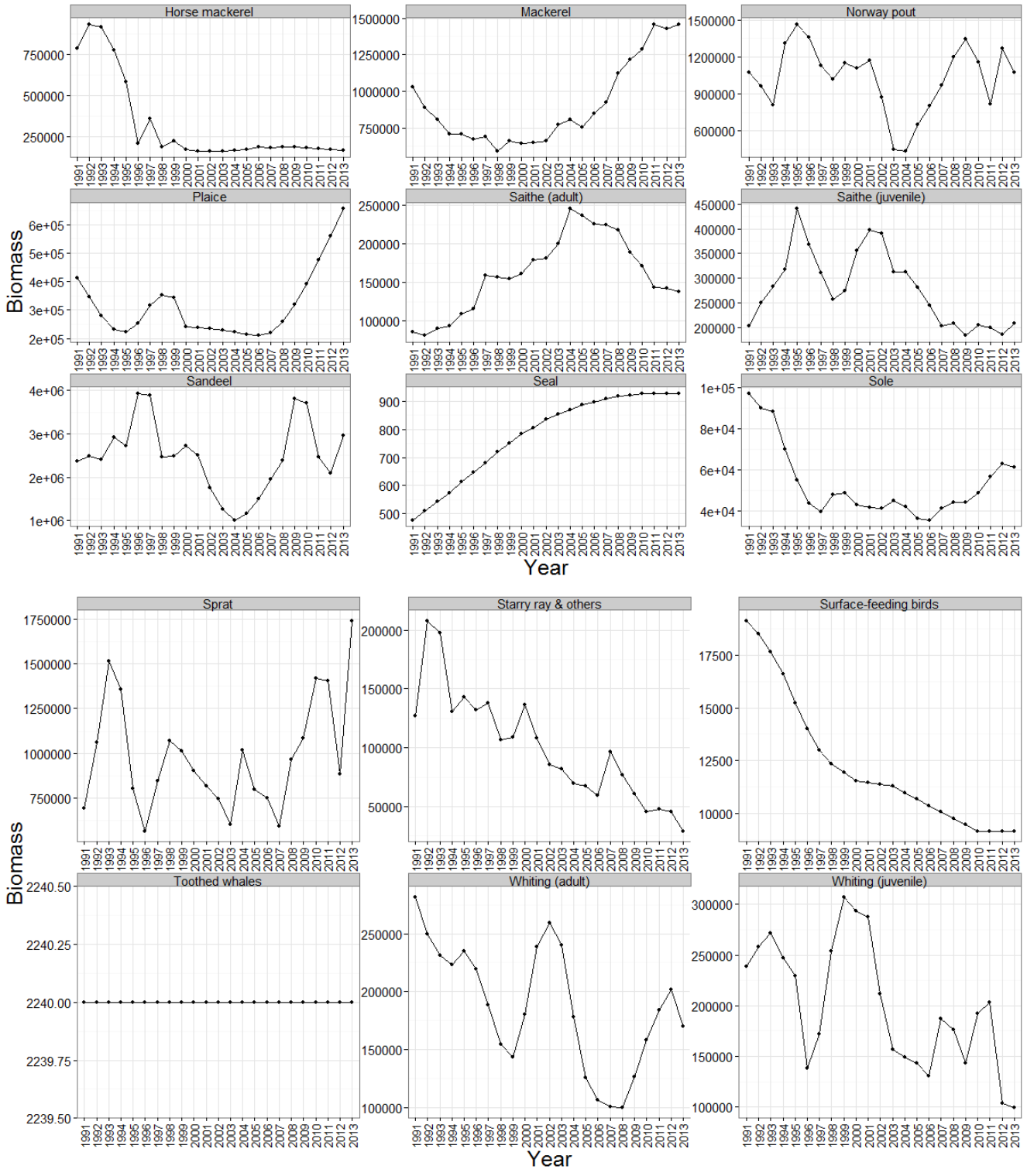


Figure 3.3 Biomass in species in tonnes (for fish groups) from the SMS model output data. Birds and mammals data are relative biomass indices.

3.2.2. Biological Monitoring Surveys

International Bottom Trawl Surveys

Each country bordering the North Sea contributes to an annual synoptic fishing survey of fish distribution and relative abundance. The survey is known as the International Bottom Trawl Survey, IBTS). Each country uses a standard approach defined by ICES, and the data are combined into a single database, known as DATRAS. The database is available on request from ICES. DATRAS also includes information from Surveys for other regions, such as the Channel and Irish Sea, but the coverage and length of time-series is most substantial for the North Sea where surveys have been undertaken since the early 1970s. The quarter 1 (Spring) surveys are taken as the best index of relative abundance.

http://datras.ices.dk/Home/Default.aspx

Source

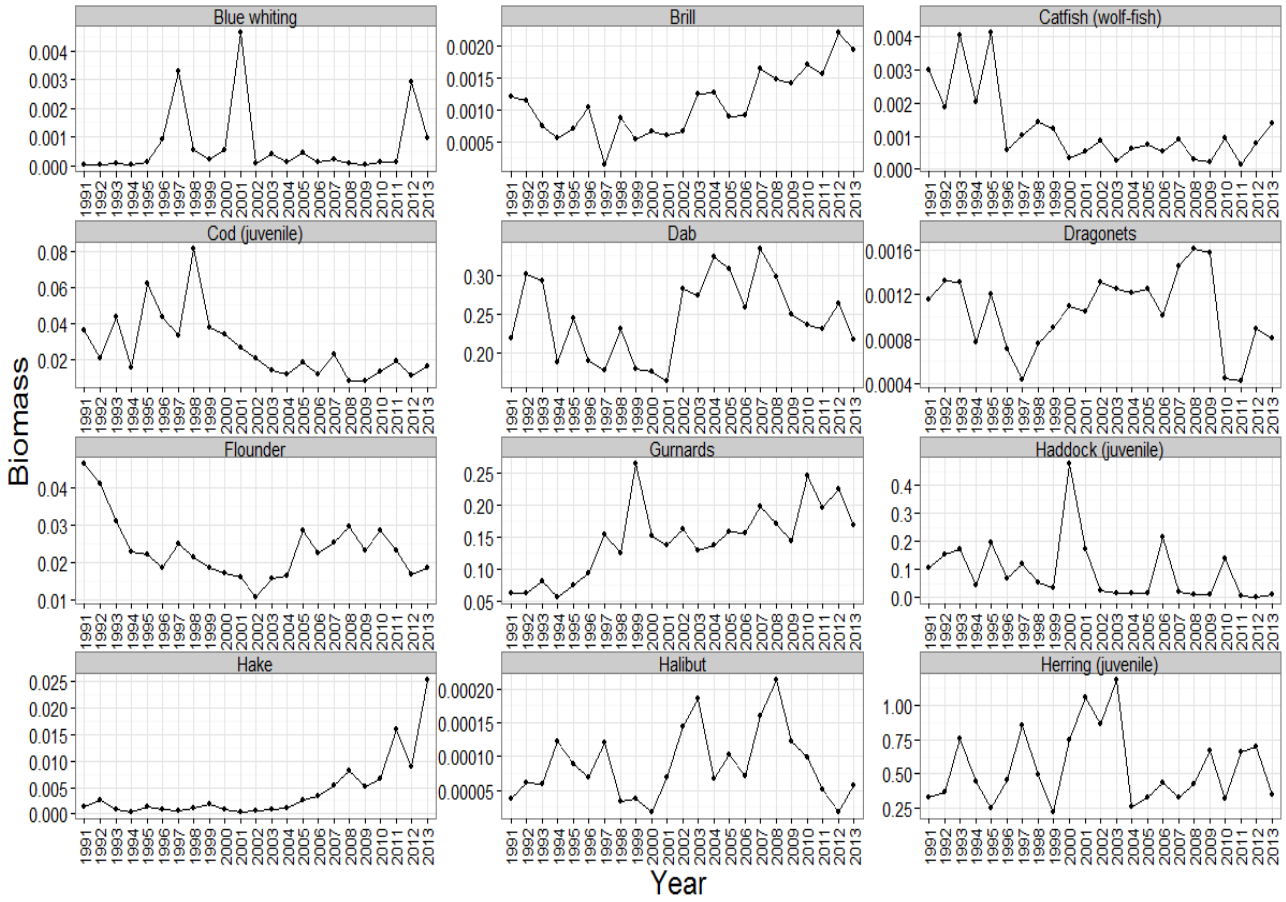
IBTS q1 exchange data were initially downloaded from DATRAS for 1991–2010 on 15 January 2013 and updated for the period 2011–2014 on 29 May 2014.

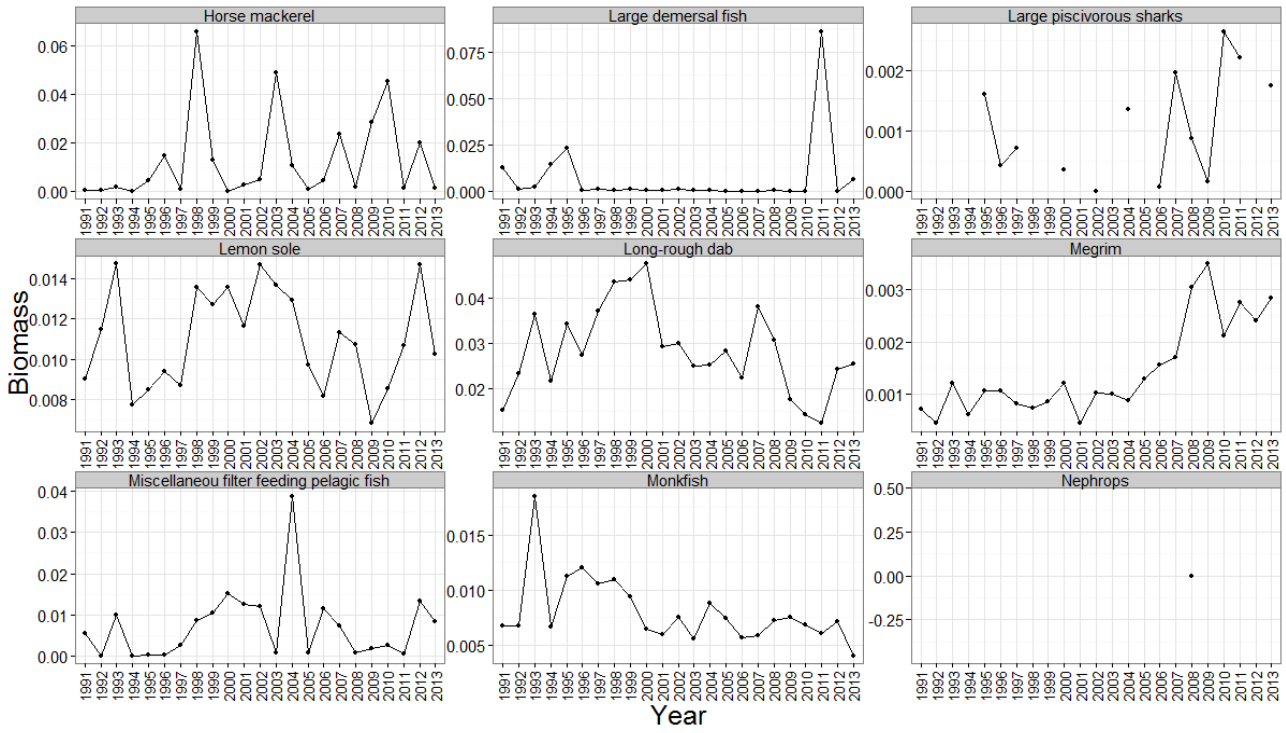
Formatting

Species number at length data were converted into biomass at length using Length-Weight relationships detailed by Fung *et al.* (2012). Estimated trawl swept areas was calculated in R from wingspread multiplied by the distance towed, where data were available. Where wingspread data were missing, wingspread was estimated from values provided for the same local area (ICES statistical rectangle) or from depth data using the protocol detailed by Fung *et al.* (2012).

Export

Formatted data were exported in .csv format with estimated catch per swept area per functional group and per year (Figure 3.4)


Blue whiting
Brill
Catfish (wolf-fish)
Cod (juvenile)
Dab
Dragonets
Flounder
Gurnards
Haddock (juvenile)
Hake
Halibut
Herring (juvenile)
Biomass
Year


Horse mackerel
Large demersal fish
Large piscivorous sharks
Lemon sole
Long-rough dab
Megrim
Miscellaneou filter feeding pelagic fish
Monkfish
Nephrops
Biomass
Year

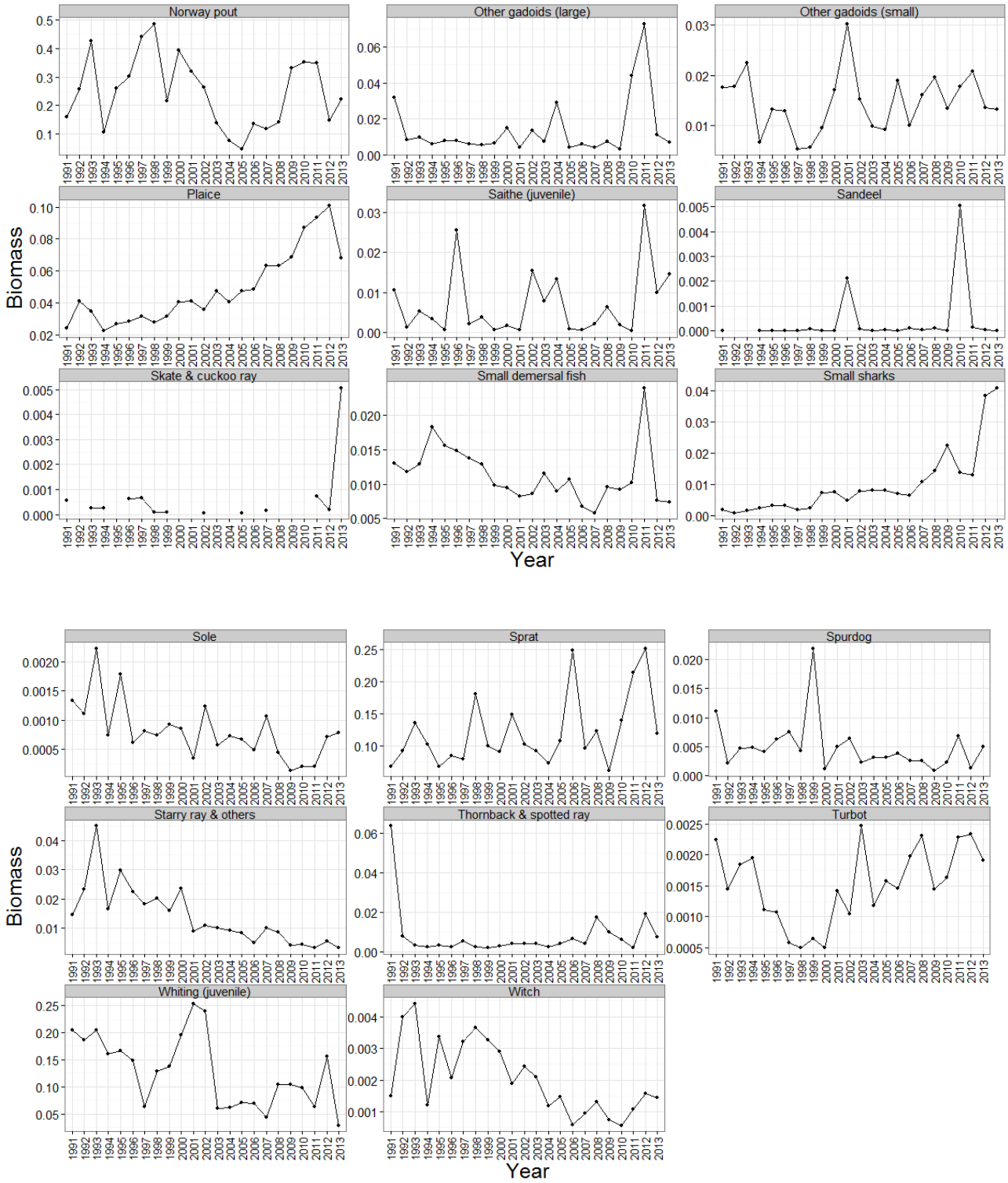


Figure 3.4. Biomass in tonnes per km² from the yearly first quarter of the IBTS campaigns data available to be used as relative biomass series to be used in model fitting.

UK National Marine Monitoring Programme for benthos

The National Marine Monitoring Programme (NMMP) was initiated in the late 1980s to co-ordinate marine monitoring in the United Kingdom between a number of organisations. The NMMP aims to detect long-term trends in the quality of the marine environment, to ensure consistent standards in monitoring, to establish appropriate protective regulatory measures, to co-ordinate and optimise marine monitoring in the UK, and to provide a high quality key dataset for key variables. Specific non-disturbed sites around the UK are sampled annually to gain an understanding of background changes in benthic communities. The data is collated by Cefas and in the North Sea includes two sites extending back to 1993.

Thames and Northumberland for benthos

The Thames (1986–2005) (MAFF 2013) and Northumberland (Tyne estuary: 1984–2006) (Rees *et al.* 2006 and Birchenough & Frid 2009) time-series are part of a long-term monitoring programme started in the early 1980s to ascertain the changes resulting from sewage slugde disposal. Only the reference stations (non impacted by sewage disposal) are usable for the present model and includes three stations; the data is collated by Cefas.

Source

NMMP data are held on the Cefas Unicorn database and are available upon request on one of the authors of this document or on the NMMP data manager (Thomas Maes: Thomas.maes@cefas.co.uk). The Thames and Northumberland time-series are also held on the Cefas Unicorn database and also available upon request to (Silvana Birchenough: Silvana.birchenough@cefas.co.uk).

Formatting

The first step is to establish a species average biomass using data for which abundance and biomass are available. In the vast majority of cases, abundance is the only quantity available in these data, therefore to obtain a biomass time-series it is necessary to the reference to determine an average biomass per species. Species biomass of all replicates is summed to have one value per station and per year. Each species is affiliated to a EwE functional group and all biomass is summed to obtain one value per functional group per station and per year. Biomass values are finally averaged across all stations and exported.

Export

Formatted benthic data are then exported under a .csv format and present a value per functional group and per year for the biomass of the different benthic functional groups (Figure 3.5)

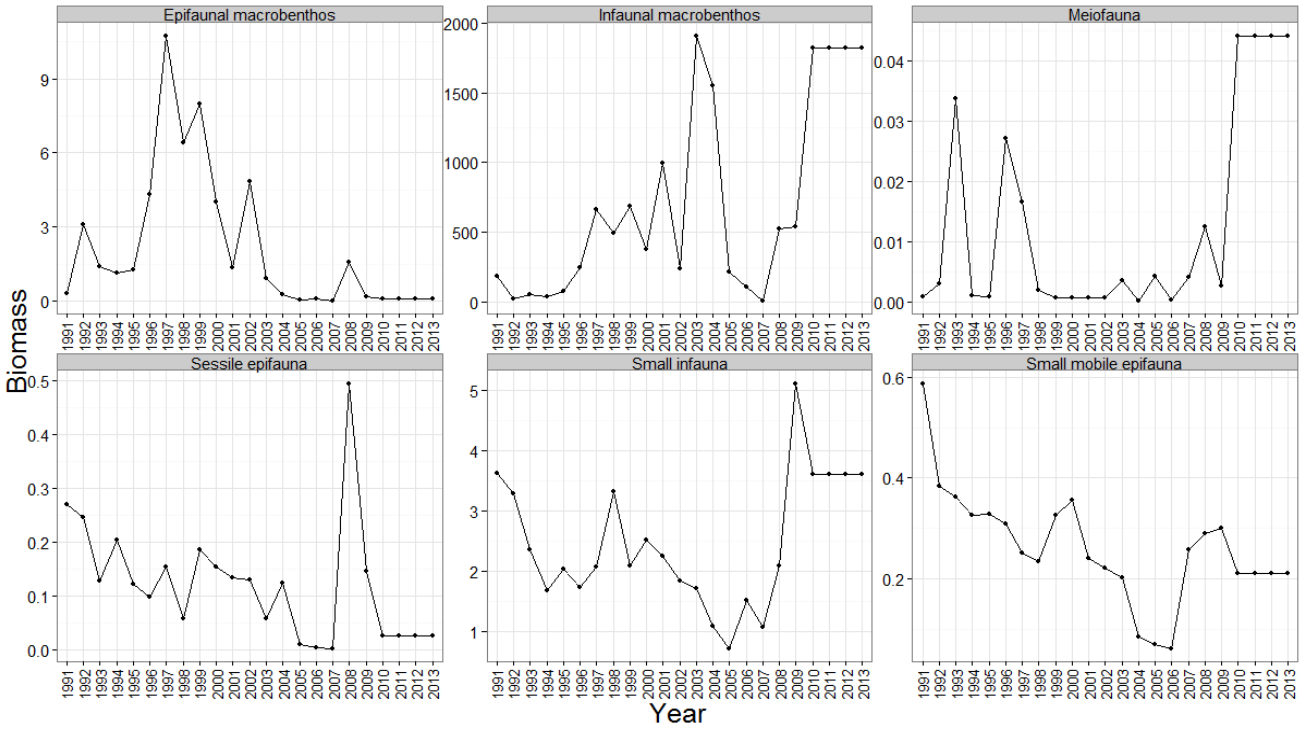


Figure 3.5. Biomass in tonnes of WW from Cefas National Monitoring programme for the benthic group available to be used as relative biomass series to be used in model fitting.

Plankton monitoring data

Source

Continuous Plankton Recorder (CPR) data on zooplankton and phytoplankton in the North Sea 1958–2013 were provided by SAHFOS (David Johns, Priscilla Licandro, emails 18/11/14). (Ref: Johns, 2014).

In addition, estimates of annual gross primary production of the North Sea were calculated using an empirical relationship (Cloern 1987), based on chlorophyll concentration, surface irradiance and light attenuation. In particular, all available in situ measurements of chlorophyll and light attenuation (from light profiles and from estimates of Suspended Particulate Materials), for the southern and central North Sea, were collated from different data sources (e.g. ICES, Cefas). Measurements were then analysed based on 5 hydrodynamic regions with distinct stratification regimes (van Leeuwen *et al.* 2015), and used in the empirical model for calculating production. Missing values of chlorophyll and light attenuation were generated statistically from existing available data.

Formatting

Zooplankton species were grouped in to ominivrous, herbivorous and carnivorous classes based on Llope *et al.* 2011 (supplementary). Phytoplankton data consisted of total counts of diatoms and dinoflagellates and the Phytoplankton Colour Index (PCI). Point data were combined to provide annual averages covering ICES div IVa,b,c.

The estimates of primary production based on chlorophyll concentration were used in preference to the CPR data because they are based on chlorophyll concentration (proxy for phytoplankton biomass) and on the light climate (one of the environmental factors affecting plankton production), and also because they were calculated for the upper 20 m of the water column (where the majority of production is expected to occur).

Export

Data were exported as csv and included as relative biomass time-series to fitting. Zooplankton data (CPR Sahfos) & Primary Production dynamic (Capuzzo pers. Com.): Figure 3.6.

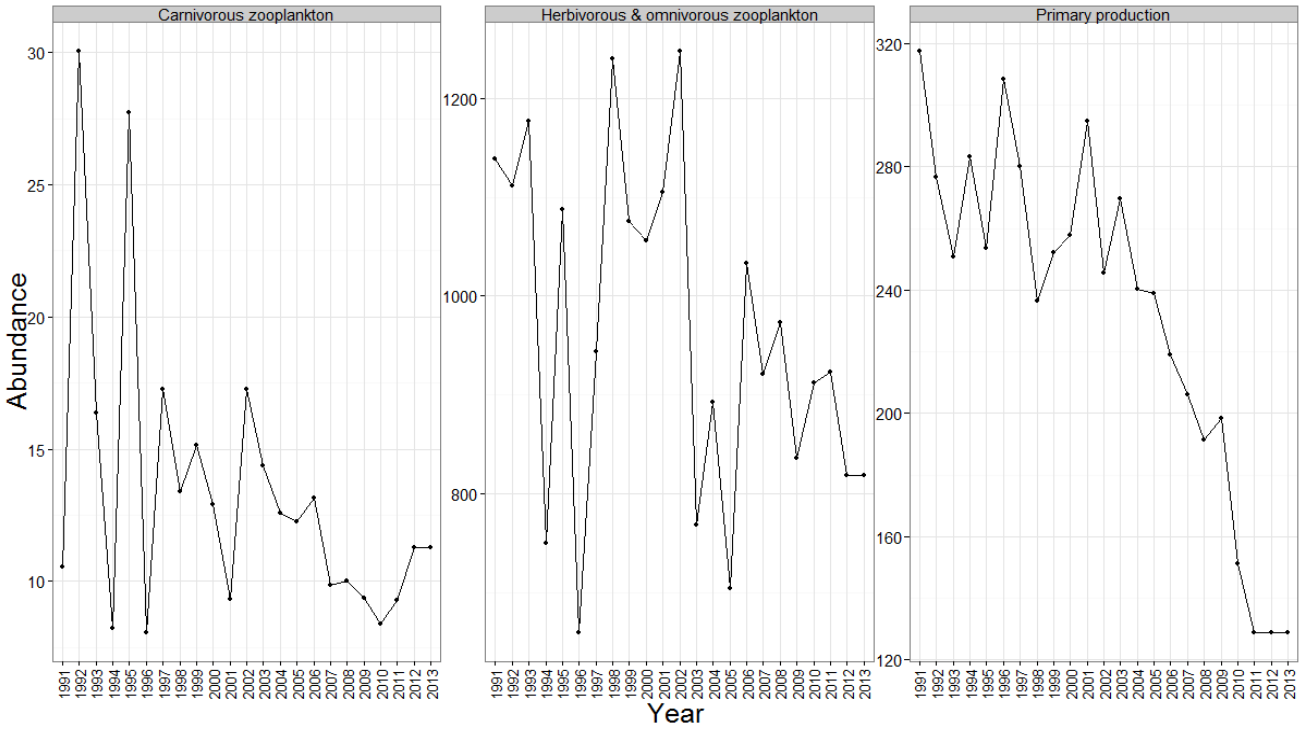


Figure 3.6. Abundance of zooplankton (CPR counts) and primary production (chlorophyll concentration gC m^2. y^1) time-series data available to be used as relative biomass series to be used in model fitting.

3.3. Fishing catches, effort and mortality

3.3.1. ICES Catch and Landing data

Catch data from stock assessments (Figure 3.7, 3.8) were treated in the same way as biomass data (see 3.2.1).

ICES also collates international databases on fisheries landings, which includes landings of fish and shellfish from 20 countries, for each species at the spatial resolution of an ICES division. In the North Sea, there are 3 divisions, IVa,b,c. The current data is collected and coordinated in collaboration with Statistical Office of the European Communities (EU-

ROSTAT). ICES have published these data in the Bulletin Statistique des Pêches Maritimes from 1903 to 1987, and from 1988 onwards in ICES Fisheries Statistics. The database provides a comprehensive catalogue of reported landings for 223 North Sea species. Unfortunately they are not broken down by gear type. The landings database is accessed and manipulated using an FAO database query tool called Fishstat. Fishstat can also be used to query the FAO international fisheries landings data collated by themselves.

Source

The landings statistics from ICES are free available from the following link: http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx. Two datasets are available depending on the time range, the historical dataset (1950–2010) and the current dataset (2006 – to date); only the routine developed to format the current dataset will be presented here, the historical dataset differs mostly by the nomenclature of the different column headers however.

Formatting

As above data formatting was done using the free statistical software R; the following parameters are needed: species, country and divisions. Only division "IV" is selected, which is the sum of the division "IVa", "IVb" and "IVc", then the sum of the landings of each country per species and per year is calculated. Each species is then related to one of the EwE functional group using our look up table and their landings biomass values are then summed to obtain one value per group and per year.

Export

Formatted data are then exported under a .csv format and present a value per functional group and per year for landings (Figure 3.9).

The datasets from 1950–2010 and 2006 – to date are extracted from different sources; the historical data (1950–2010) is an extraction of the last copy of the FishStatPlus dataset whose support and update have now ceased; the current version (2006 – to date) is based on a dataset maintained by EUROSTAT. At the time of the reporting of this work, no acceptable compromise between the two dataset was found. We therefore used the historical (non-corrected data) until the year 2005 and then switched to the current, assumed to be best, data starting in 2006.

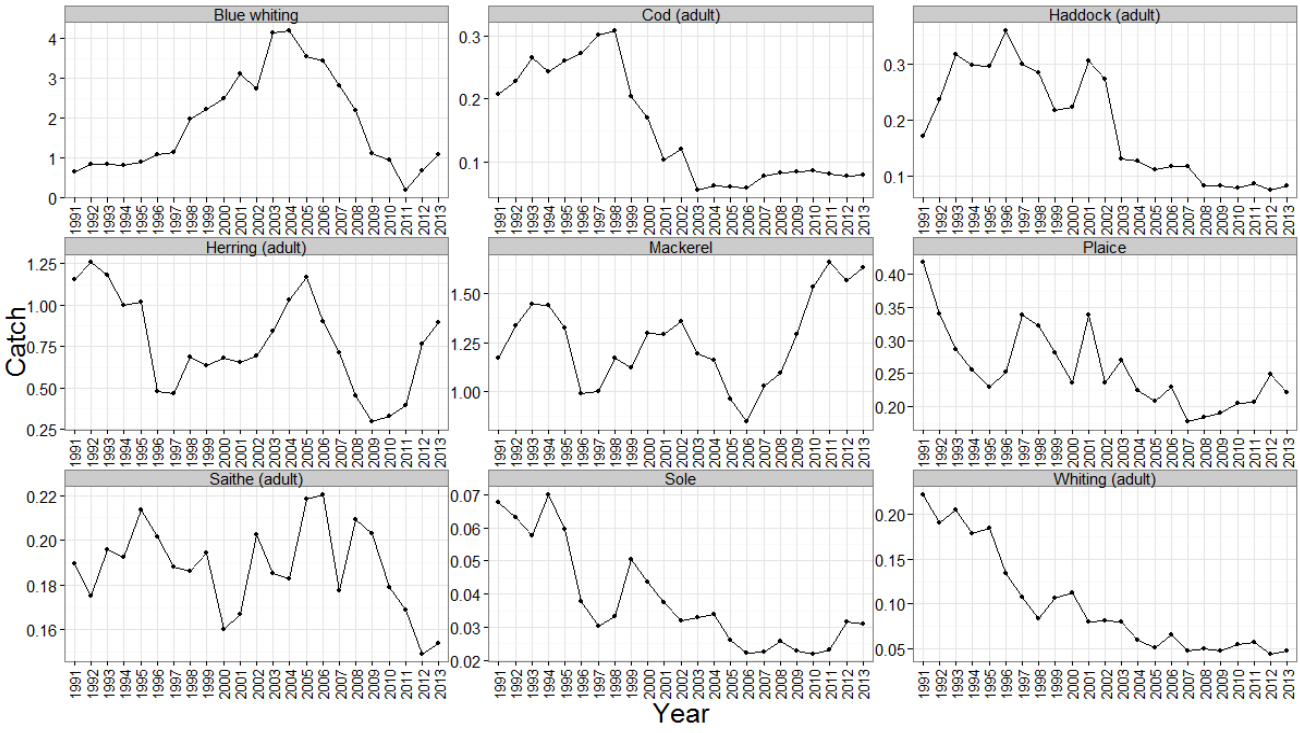
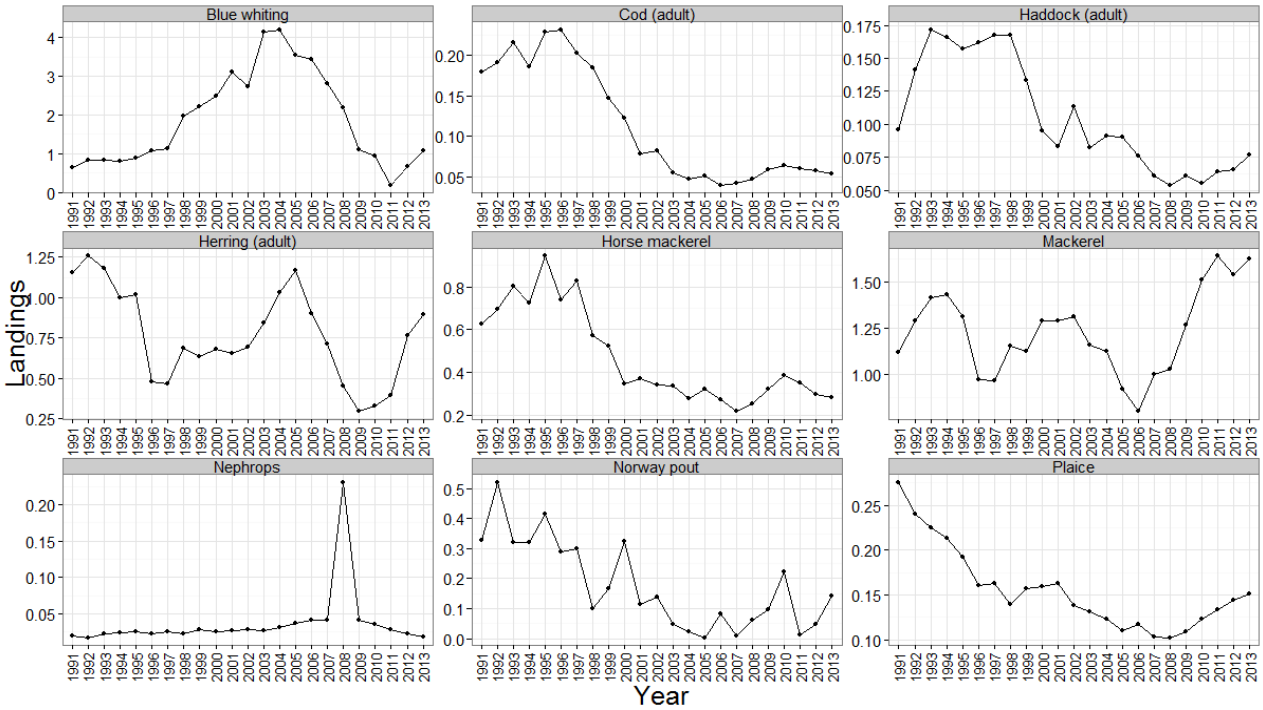


Figure 3.7. Catch data (in tonnes per km²) from single species assessments for assessed species available for model fitting.



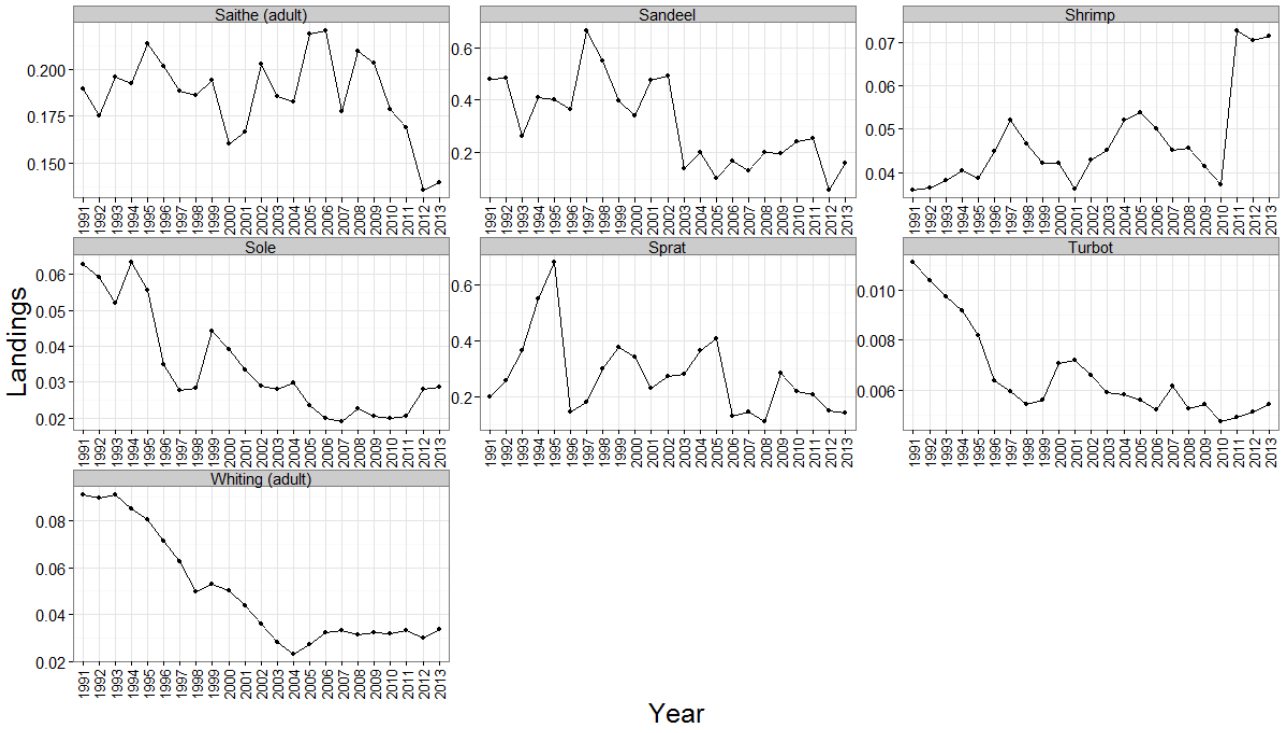
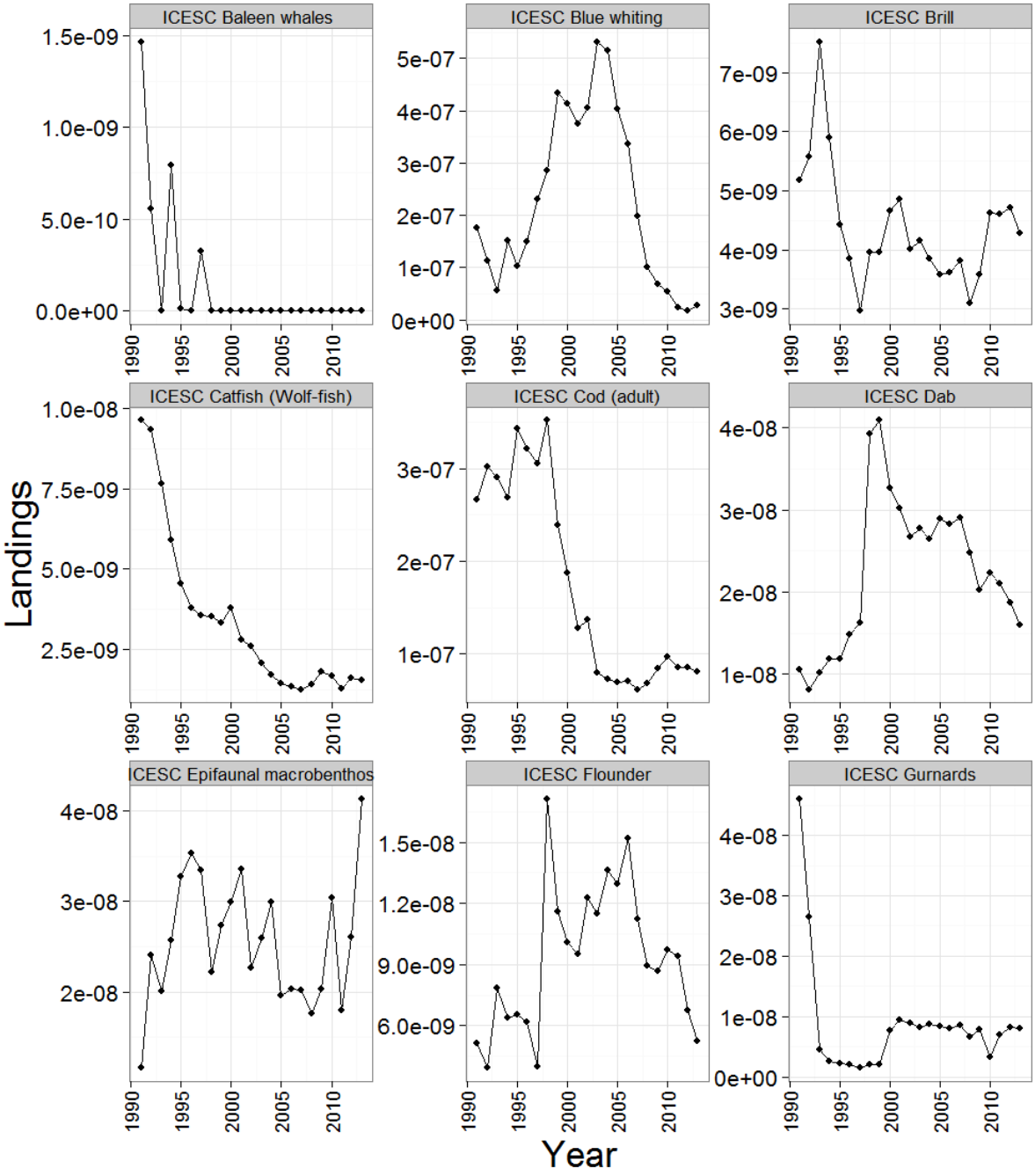
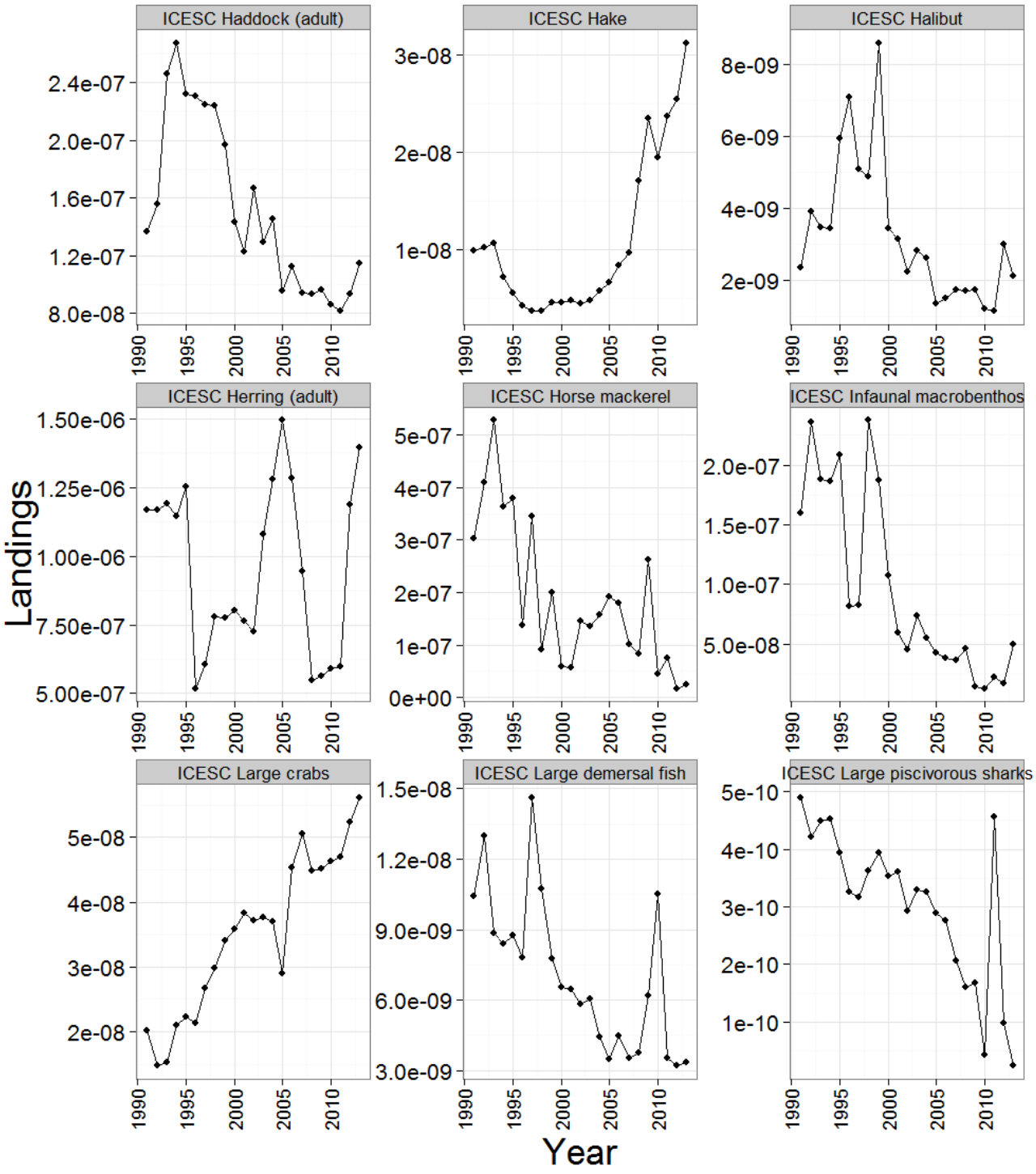
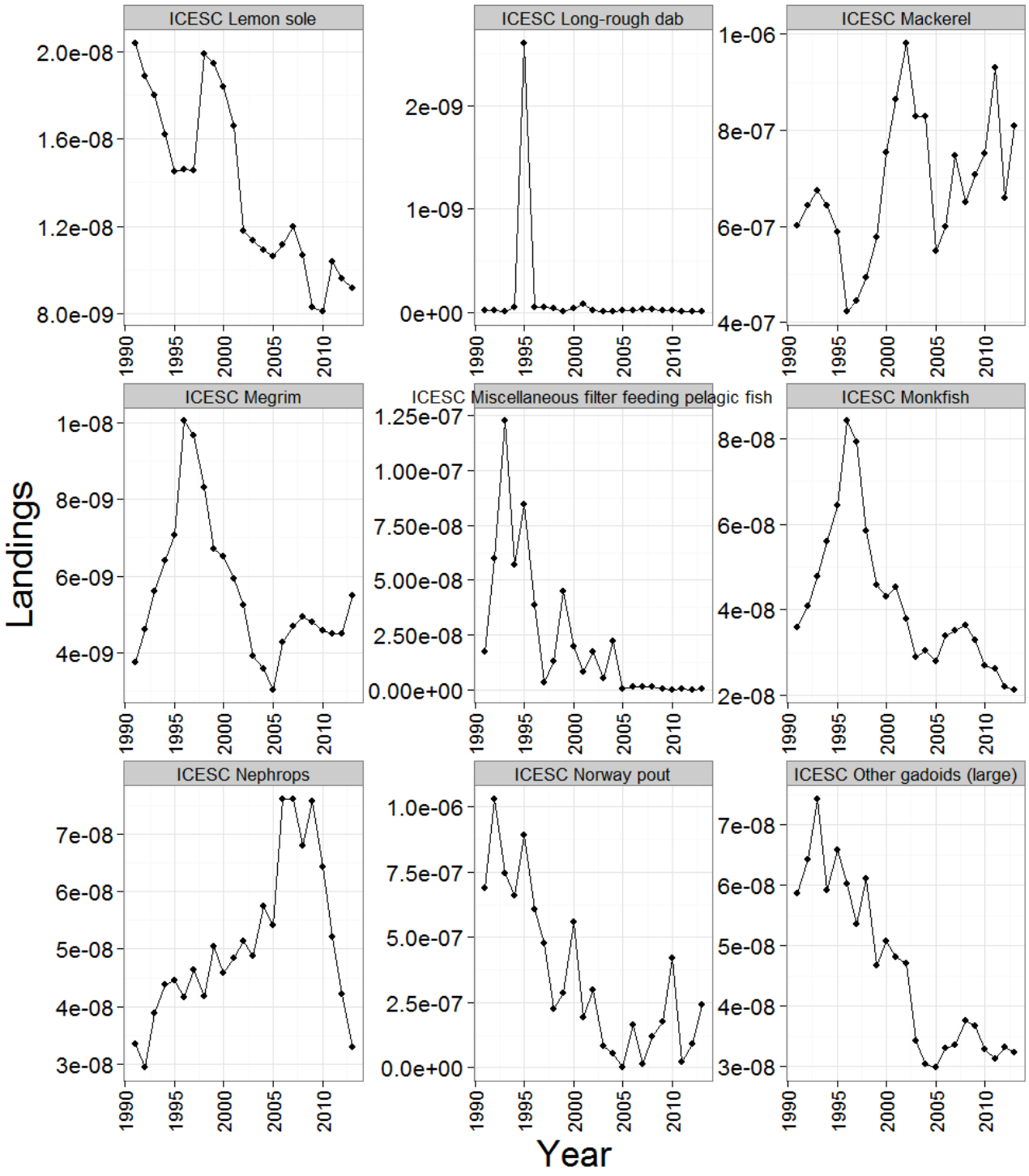
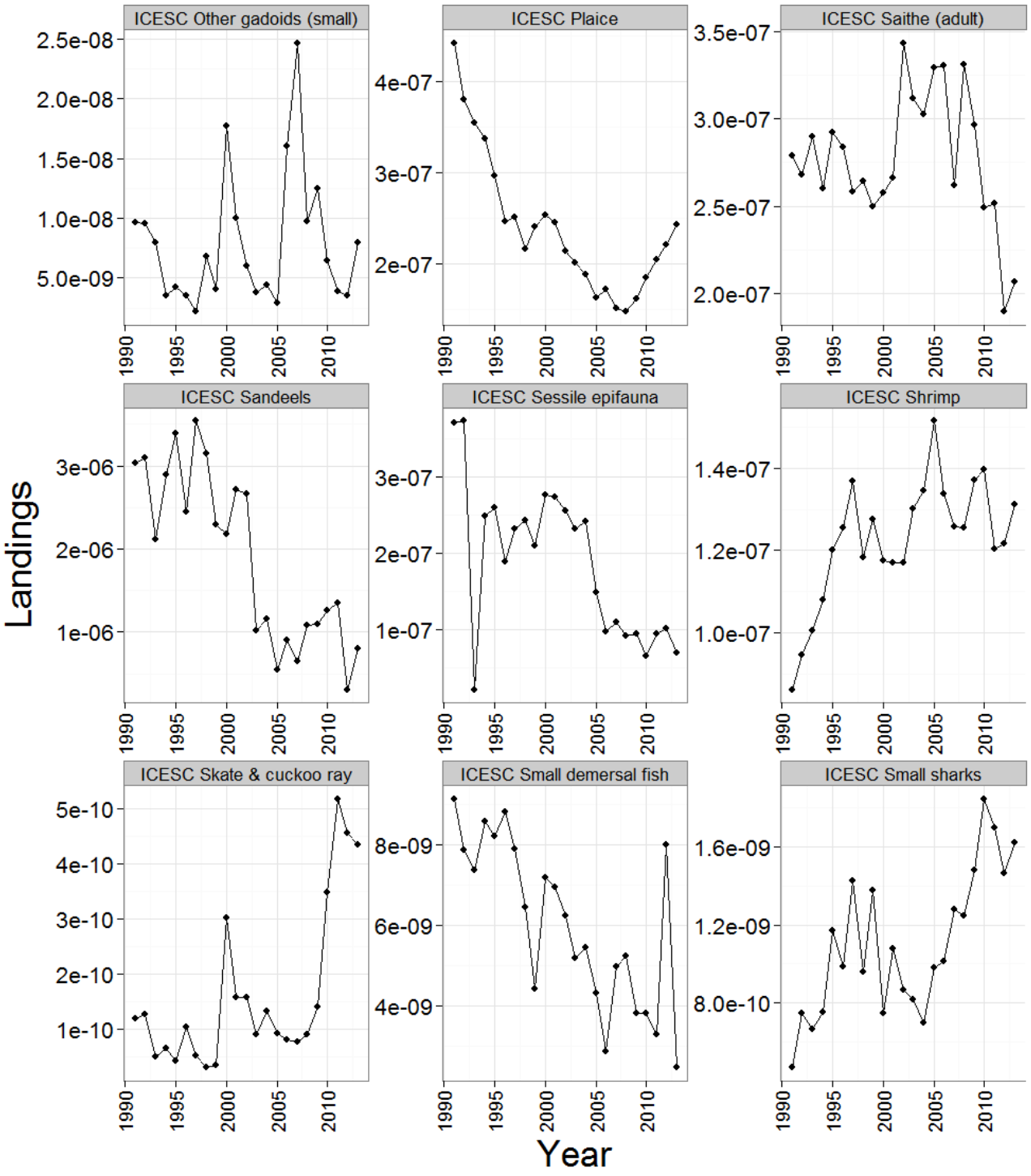


Figure 3.8. Landings data (in tonnes per km²) from single species assessments for assessed species available for model fitting.


ICESC Baleen whales
ICESC Blue whiting
ICESC Brill
ICESC Catfish (Wolf-fish)
ICESC Cod (adult)
ICESC Dab
ICESC Epifaunal macrobenthos
ICESC Flounder
ICESC Gurnards
Landings
Year


ICESC Haddock (adult)
ICESC Hake
ICESC Halibut
ICESC Herring (adult)
ICESC Horse mackerel
ICESC Infaunal macrobenthos
ICESC Large crabs
ICESC Large demersal fish
ICESC Large piscivorous sharks
Landings
Year
1990
1995
2000
2005
2010


ICESC Lemon sole
ICESC Long-rough dab
ICESC Mackerel
ICESC Megrim
ICESC Miscellaneous filter feeding pelagic fish
ICESC Monkfish
ICESC Nephrops
ICESC Norway pout
ICESC Other gadoids (large)
Landings
Year


ICESC Other gadoids (small)
ICESC Plaice
ICESC Saithe (adult)
ICESC Sandeels
ICESC Sessile epifauna
ICESC Shrimp
ICESC Skate & cuckoo ray
ICESC Small demersal fish
ICESC Small sharks
Landings
Year

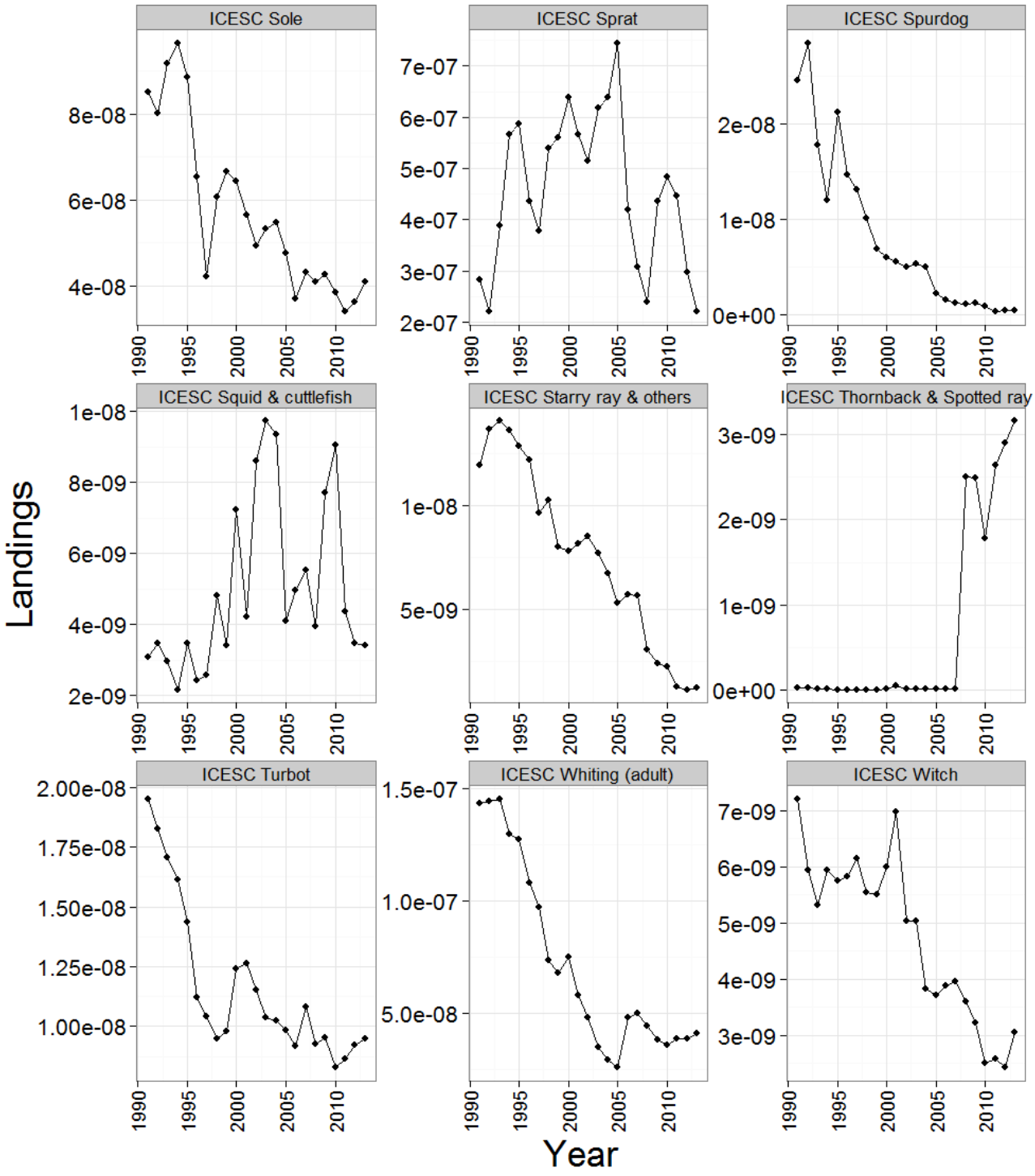


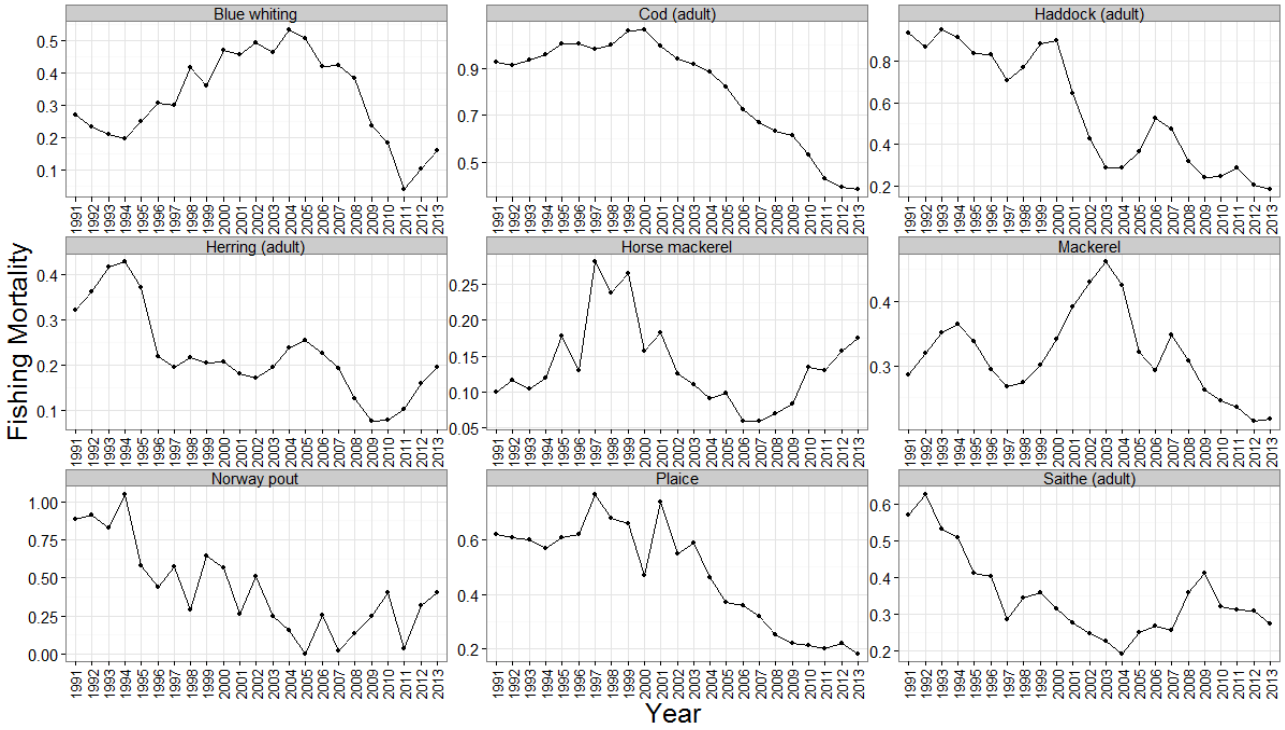
Figure 3.9. Landings data (in tonnes per km²) from the ICES catch statistics showing the discrepancies between historical (blue) and current (red) data available for model fitting.

3.3.2. Fishing mortality and effort

Fishing mortality

For assessed species, fishing mortality time-series were taken from the ICES single-species assessment data Figure 3.10.

For *non-assessed groups*, Ecosim calculates a fishing mortality time-series for each group by taking the partial fishing mortality estimates for each group-fleet combination that is defined in the ecopath model base year (1991 here) and multiplying them by time-series data on the relative effort of each fleet (see below). This results in a partial fishing mortality time-series for each group-fleet pair, which is summed to provide a time-series of fishing mortality on each group. Thus, although relative effort series are used as 'input' to Ecosim, it is the calculated fishing mortality on each group that is used to drive the model.



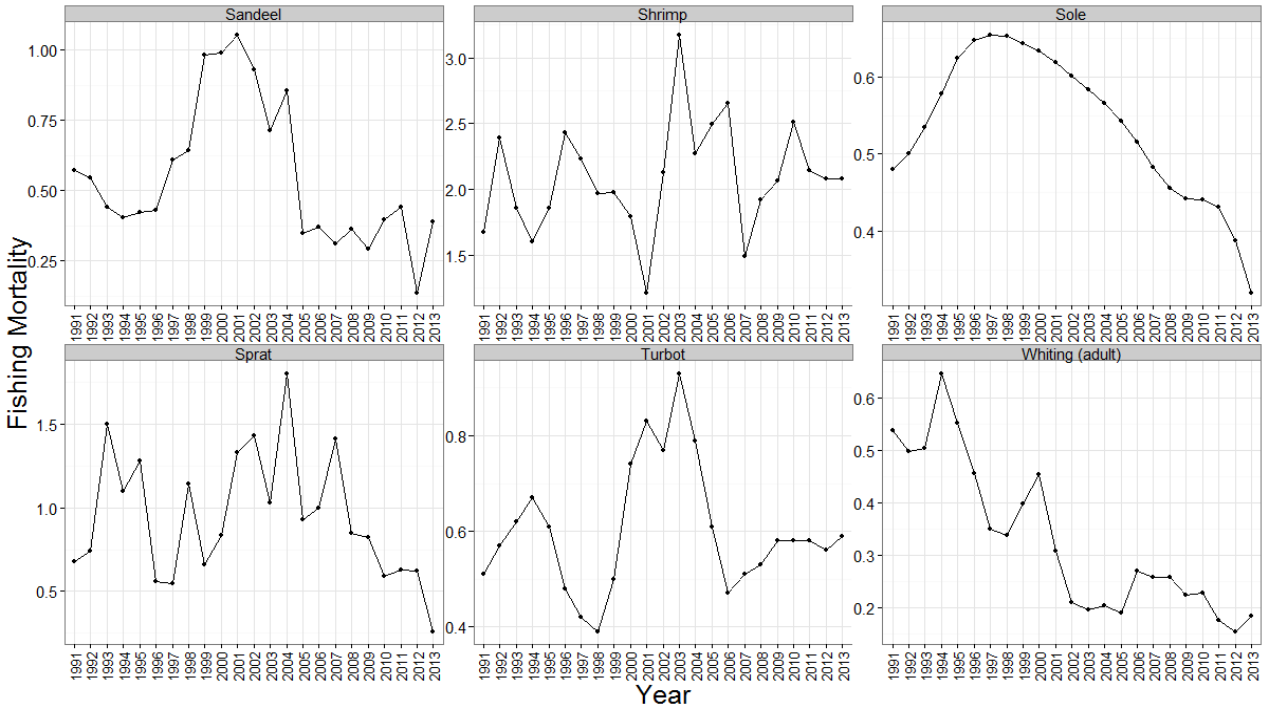


Figure 3.10. Fishing mortality data for assessed species used to drive changes in the model.

Fishing effort

Data on the fishing effort, landings and discards of fleets in the North Sea 2000–2012 have been collected under the Data Collection Framework (DCF); (formerly DCR). Data prior to 2000 used in the previous key run were obtained from ICES Working Group reports and Scientific and Technical and Economic Committee for Fisheries (STECF) effort working group reports (see previous key run documentation). https://stecf.jrc.ec.europa.eu/data-reports.

Source

Data on fishing effort of fleets in the North Sea from 2000–2012 were obtained from the STECF effort database (STECF 2013). https://stecf.jrc.ec.europa.eu/data-reports

Formatting

To provide a continuous series of relative effort data for each of the modelled fleets, the recent STECF data was appended to the 1991–1999 data which was obtained from STECF and ICES working groups used in the previous key run (Figure 3.11).

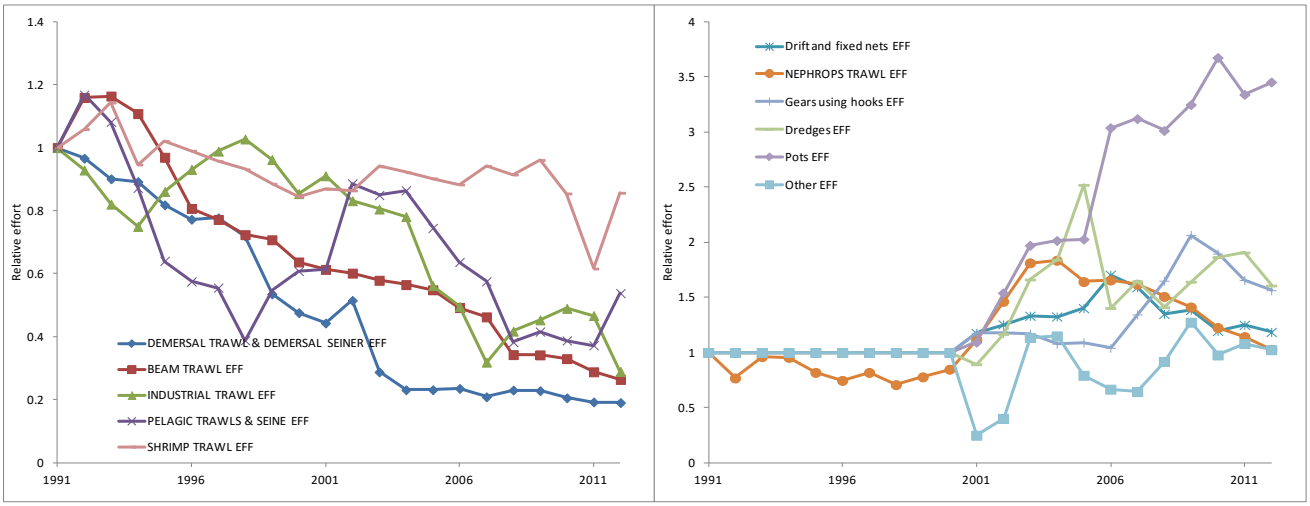


Figure 3.11. Relative effort series used in the key run (ref File: STECF effort data 2013_Industrial fleet.xlsx).

Export

Data were exported as csv to the time-series file.

Total mortality (Z)

The mortality coefficient is a combination of fishing mortality, predation mortality and other mortality. Time-series for this parameter were taken from the output of the multi-species assessment model SMS. The total mortality from SMS is not fitted to during calibration but used to compare the outputs of EwE with SMS (see section 5).

3.4. Environment

Numerous sources for environmental time-series data already exist on the internet. Some provide series of direct observation measurements such as temperature and salinity, while other provide composite indices (e.g. NAO, Gulf Stream Index, AMO). Table 3.1 identifies those used in the model parameterisation. A key resource for environmental time-series data is Climate Diagnostics Center, National Oceanographic and Atmospheric Administration of the US Department of Commerce (www.cdc.noaa.gov).

http://www.esrl.noaa.gov/psd/data/climateindices/list/

The research for data underlying physical explanatory variables was restricted to what were considered to be driving the most amount of variance in the time-series dynamics – the North Atlantic Oscillation (NAO), the Atlantic Multidecadal Oscillation (AMO) and the Sea Surface Temperature (HadSST); (Figure 3.12). Previous work had undertaken extensive correlation analyses to identify relationships between pressure and state variables; the analysis was broken down into two distinct periods. The first covered the data

period used in the model simulations 1991–2007, the second corresponded to the full length of the data set, 1950–2007, where longer term patterns could be investigated. Details are provided in Mackinson (2014).

Examination of alternative parameterisations used in calibration of the model, together with prior evidence from analysis of empirical data Mackinson (2014) revealed links between environmental indices, changes in primary production and species biomass trends across a broad range of functional groups. Based on this evidence, environmental data were used to define a forcing function describing bottom-up changes in primary production (PP anomaly) and to modify specific trophic interactions in some functional groups (see Table 4.5).

North Atlantic Oscillation (NAO)

Source

The Hurrel index for the North Atlantic Oscillation (NAO) from 1864 to 2014 obtained from Hurrel, J & National Center for Atmospheric Research Staff (Eds.). Last modified on 20 June 2014. "The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (station-based). Retrieved from https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based.

Formatting

The index is calculate on a monthly then annual basis by selecting the average of winter month values only (December to February); (Dye pers. Comm.). No formatting was necessary since the dataset was retrieved with one value per year already.

Export

Formatted NAO index data are then exported under a .csv file and present a value per year (Figure 3.12).

Atlantic Multidecadal Oscillation (AMO)

Source

The Atlantic Multidecadal Oscillation time-series data are available from the Earth System Research Laboratory website on the following link:

http://www.esrl.noaa.gov/psd/data/timeseries/AMO/ . Smoothed and unsmoothed data are available but the smoothed data stops in 2011 so far, therefore only the unsmoothed data were downloaded.

Formatting

The raw data are given in monthly value and the annual average was calculated across all the months for each year.

Export

Formatted AMO index data are then exported under a .csv file and present a value per year (Figure 3.12).

Hadley Sea Surface Temperature (HadSST)

Source

Hadley Sea Surface Temperature (HadSST) was downloaded from the metoffice website http://www.metoffice.gov.uk/hadobs/hadsst3/data/download.html. The monthly value for the whole world was downloaded: HadSST.3.1.1.0_monthly_globe_ts.txt.

Formatting

The data formatting was done using R (R Core Team 2014). These data are georeferenced (each value correspond to a square latitude/longitude). We have selected the months ranging from 1991 to 2014 and focused on the "squares" corresponding to the North Sea geographical coordinates (51 to 62N latitude and 4W to 9E longitude). The temperature values across all the square selected is averaged per month to have one value per months for the North Sea and finally averaged across all months to have one value per year.

Export

Formatted Hadley SST values data are then exported under a .csv file and present a value per year (Figure 3.12).

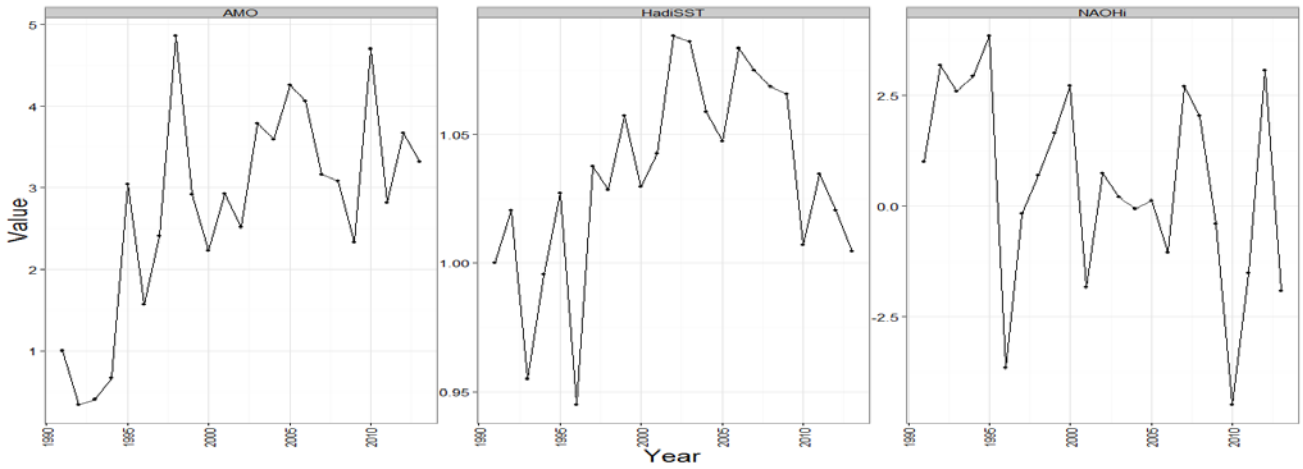


Figure 3.12. Environmental indices used as drivers in model fitting, climate indices – NAO, AMO and Hadley Sea surface temperature.

4. Ecosim fit to data

4.1. The process of fitting the model to data

The process of fitting the model to observation data is described in the following series of steps, with supporting information cross referenced in the sub-sections below.

1. Selection of the best time-series based on a quality assessment (section 4.1.1, Tables 4.1, 4.2, 4.3).
2. Weighting the time-series such that long term trends are emphasised more than interannual variability (section 4.1.2).

3. Assessing the sensitivity of the performance of the model fit to changes in the vulnerability of each functional group (by predator), and identifying a parsimonius breakpoint in the number of vulnerability parameters estimated and the model fit. This indicated 15 sensitive groups. (Figure 4.1).

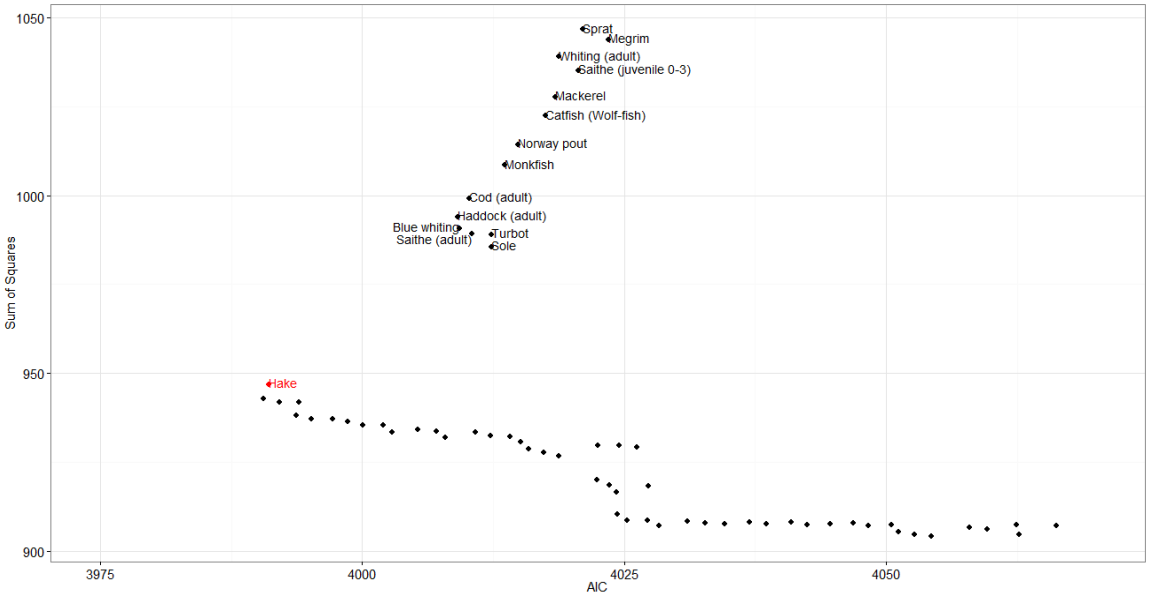


Figure 4.1. Plot of sensitivity to the number of vulnerability parameters estimated. Each point represents one vulnerability parameter. It shows that the first 15 vulnerabilities (from sprat to hake) provide a good balance between the fit based on sums of squares and AIC. Beyond 15 parameters the low gains in Sums of squares are not considered to outweigh the higher AIC.

4. Using the non-linear fitting procedure in Ecosim[1] to estimate the vulnerability parameters for the top 15 most sensitive groups and all the assessed stocks plus 2 plankton groups (as in the previous key run). This meant there were 27 functional groups for which the vulnerability parameter was estimated.
5. Estimating a primary production anomaly at the same time as estimating v's, such that the anomaly when applied to primary production, led to improvements in the model fit, assessed by AIC to take account of the additional parameters.
6. Evaluating the quality of the model fit to data, both globally and for each individual functional group using sums of squares and AICc criteria to assess the goodness of fit and account for differences in the number of parameters estimated by the alternative model parameterisations.
7. Examining the influence of the vulnerability parameters estimated by Ecosim on the predictions of (i) the model estimates of Fmsy when species interactions are accounted for, and (ii) the degree of compensation in recruitment for multistanza

[1] Ecosim uses a Marquardt nonlinear search algorithm with 'trust region modification' of the Marquardt steps to search for vulnerabilities that improve the fit of model predictions to time series observations.

groups (cod, haddock, whiting, saithe, herring) (ii). See point 10 and section 4.1.3.

NOTE 1: The need to simultaneousy reproduce observed patterns in biomass trends as well as make credibile predictions of Fmsy, necessitates taking a Pattern Oriented Modelling approach (Grimm *et al.* 2005; Kramer-Schadt *et al.* 2007), where the criteria for the model performance is not solely based a statistical measure of goodness of fit (see Heymans *et al.* 2015).

Examining model predictions of sustainable fishing rates (Fmsy) is particularly important for calibrating models intended to be used in operational advice because the degree of compensation in recruitment affects how resilient stocks are to fishing and consequent estimates of Fmsy. Accordingly, Fmsy estimates are key indicators of model behaviour. When vulnerability estimates are low (v=1), Ecosim predicts very high compensation in recruitment and very high rates of Fmsy. These estimates would not be considered plausible based on what is known from single species assessments and maximum rates of F that have led to stock depletions in the past. When v estimates are higher (v=2 to 10 or more), predictions of Fmsy start to come in to a plausible range.

8. At this stage in the preparation of the key run, we found that the model fit with the least sums of squares occurred when vulnerability for many groups was near to 1. This resulted in a dilemma (already discussed in Mackinson 2014), where the prettiest model fit to data did not yield credible beahviour in terms of predictions of rates of population recovery, depletion and Fmsy. In Ecosim, vulnerabilities represent the ratio of the maximum possible prey mortality rate caused by a predator, if the predator was much more abundant. This means that when dealing with species that have been greatly reduced (in both adult biomass and recruitment) by fishing over the long term, higher vulnerability multipliers are needed in order for the model to predict recovery to the historical levels if fishing was ceased. These high multiplier values also result in higher sensitivity of recruitment to stock size (and lower Fmsy's) whether or not they result in best fits to very short term data.
9. We reasoned that due to the limited time-series (1991–2013), the changes in biomass of many species in the model were small in relation to their historical biomass (e.g. Figure 4.2), implying that vulnerability parameters would need to be higher for the model to predict recovery to biomass levels seen in the past. We used a formula[2] based on long term changes in biomass of stocks to provide an initial estimate of vulnerability to at least try and get in the right ball park before making further manual adjustments to bring estimates of Fmsy in to a plausible range according to estimates given from other multispecies and singles species model assessments.

[2] Vulmult = [1-(Bunf/Bo)]/[1-(e/M)(Qo/Bo)], where, e is the growth efficiency (P/Q), Bunf is historical max biomass, Bo is biomass in model base year, M is the base total natural mortality rate for the predator, and Qo/Bo is the ecopath base Q/B for the species. (Walters pers. Comm. 15/10/15)

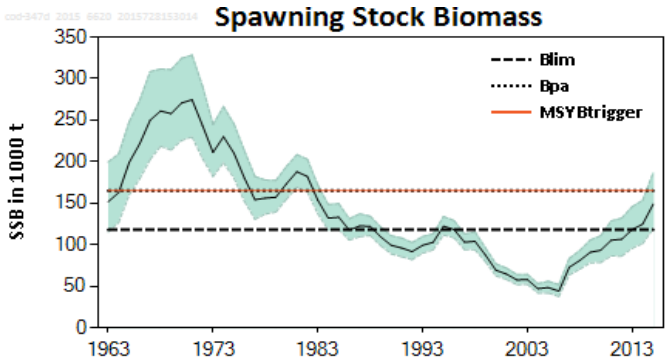


Figure 4.2. Long term changes in cod biomass in the North Sea

10. In addition, for the multistanza groups we looked at two other parameters that influence predictions of compensation in recruitment and hence predictions of Fmsy. Following the approach reported in Mackinson *et al.* (2009), careful attention was given to ensuring that the dynamics of multi-stanza groups were stable and produced credible emergent stock recruitment relationships (see section 4.1.3).
    a. Foraging time adjustments[3] were turned off for all but stanza 1 to avoid multi-stage density dependence in mortality causing net compensation to be too strong and lead to high predictions of Fmsy (Walters pers. Comm. 6/10/15).
    b. Values of wmat/winf (relative weight at maturity, which determines size-fecundity relationship). When wmat/winf is small, fish mature at early ages, and it is quite possible for the 1st and/or 2nd "juvenile" stanza(s) to produce enough eggs to sustain recruitment even when the "adult" F is very high. This is a classic prediction from equilibrium theory, i.e. that Fmsy can be infinite if size at first capture is enough larger than size at maturity for animals to have replaced themselves before becoming vulnerable (Walters pers. Comm. 16/10/15). Minor adjustments

[3] Foraging time adjustments in ecosim determine how fast organisms adjust feeding times so as to stabilize consumption rate per biomass. The value of 1 means that juveniles have a fast time response, which causes reduction in vulnerability to predation rather than increased growth rate when/if food density increases. Conversly adults of multistanzas and other groups have a value of zero, that when food is available, changes in consumption per biomass result in more rapid growth rate changes, but at the risk of higher exposure to predation.

from the previous key run were made to wmat/winf based on data for the North Sea stocks (Table 4.4).

11. Predictions of Fmsy for non multi-stanza groups were also examined, and where considered unfeasible, manual changes were made to the vulnerabilities estimated during the automatic fitting procedure.
12. At this stage, the conclusion of the adjustments to vulnerability was that all vulnerability parameters were set manually (non estimated by ecosim).
13. A primary production anomaly was estimated by ecosim, such that the anomaly when applied to primary production, led to improvements in the model fit. This was correlated it with environmental time-series data to look for evidence for reasoned justification for its use.
14. Examined the contribution of each functional group to the overall performance of the fit and looked for patterns in the residuals.
15. Where patterns in time-series or their residuals were correlated to environmental time-series and there was other published evidence to suggest a link, we tested the use of environmental drivers on the consumption rate of individual function groups. In particular, there was a strong link of the cod time-series to temperature (Table 4.5). This was the same approach as applied in the previous key run (ICES 2011) and also detailed in Mackinson (2014).

16. **Following expert review of the draft Key Run presented to WGSAM 2015 (9–13 November 2015), the following changes were made:**
    a. As a proxy for changes in early year consumption effects on survival and growth, recruitment data were used to force consumption rates of juvenile multi-stanza groups. The rationale for this is that the recruitment data reflect the combined outcome of factors influencing survival of early life stages, much of which is related to their accessibility to food and thus how fast they can grow out phases of high predation. Because the recruitment trends determine to a large extent the trends in spawning stock biomass data, it's important in Ecosim to try and capture the trends in the juvenile stanza. This approach allowed us to do that.
    b. Biomass trends of seals, hake and gurnards were forced. These are important predators whose populations have seen large increases that were not possible to represent well with the model, but are known to have important effects on other groups.
    c. Twenty four vulnerability parameters and a primary prodution anomaly (4 spline was best) were estimated to provide the 'prettiest' fit to the data. These were then modified manually such that the model predictions of Fmsy were consistent Fmsy rates predicted by other multispecies, and (secondarily) single species models. This was the approach agreed during the expert review of the key run (see section 1 on quality assurance).

17. The result is a model that is driven by fishing mortality, fishing effort, primary production and trophic forcing functions, which provides a reasonable fit to the time-series data, and importantly, makes plausible predictions of Fmsy. As reported in the previous key run, the steps to ensure sensible model behaviour generally serve to worsen the model fit to data. Prettier fits can be achieved (Figures 4.11 and 4.12) by applying the vulnerabilities estimated by the fitting routine, but they do not provide the basis for credible predictions. Thus in the key run, we accept a model whose fit is less convincing but whose behaviour is more consistent with the evidence and experience from fisheries science.

Table 4.5. Consumption forcing functions applied to specific functional groups.

Forced group	Consumer forcing function	Function name	Function number
Cod (adult)	Inverse Temperature	Orig_SST RAW (INV) Loess	8
Whiting (adult)	Inverse AMO	stand AMO INV	6
Herring (adult)			
Cod (juv)	Recruitment	Cod Recruit (Juv)	9
Haddock (juv)	Recruitment	Haddock Recruit (Juv)	10
Whiting (juv)	Recruitment	Whiting Recruit (Juv)	11
Herring (juv)	Recruitment	Herring Recruit (Juv)	12
Saithe (juv)	Recruitment	Saithe Recruit (Juv)	13
Mackerel		Orig_AMO RAW Loess	5
Starry ray		stand AMO INV	6

4.1.1. Choice of the time-series used in fitting

Table 4.1 describes the approach for selecting the time-series used in model fitting. Where multiple relative biomass or catch (or landings) time-series existed, only one time-series per functional group was chosen to fit to (Table 4.2 & 4.3); this being the one considered most reliable and complete.

Relative biomass data included ICES single species assessment data, SMS multispecies assessment data, IBTS survey, ICES advice report, benthic data, plankton data. We considered the ICES singles species assessment to be the highest quality and most trustworthy data, followed by the ICES advice report then the multispecies SMS assessment and finally the IBTS survey (Table 4.2).

Similarly, the catches (or landings) time-series were ranked from the highest to the lowest quality (Table 4.3).

Table 4.1. Selection and prioritisation of data used in model calibration 1991–2013.

VARIABLE	PRIORITY DATA	SECONDARY DATA
Pressure variables		
Fishing mortality	Estimations from single species assessment models were prioritised because they are accepted and applied in fisheries management.	Estimates from multispecies models (SMS key run 2014) used when single species assessments were not available. Fishing effort data from STECF used to derive fishing mortalities for non-assessed species.
Environmental	Primary production anomaly estimated by Ecosim with justificable evidence for its use. Environmental forcing of consumption of specific groups based on analysis of residuals and existing scientific evidence (see Mackinson 2014).	
State variables		
Relative biomass data	Biomass estimates from single species stock assessment models. The advantage of assessment data is that the high variability that arises from spatial and temporal patchiness observed in surveys and causing misleading trends is avoided.	Surveys were used for non assessed species. They provide a useful overall index but can display high inter-annual variability due to patchiness in survey data. Estimates from multispecies models (SMS key run 2014) were used for some groups when single species assessments were not available.
Catch data	Single species assessment data where possible because in many instances it includes an estimate of discarded fish and thus more closely reflects removals.	For non assessed species, ICES landings data are used.

Table 4.2. Choice of the relative biomass time-series used for model fitting for each functional group. Cell open: time-series available, cell shaded: time-series unavailable, √: time-series selected, X: time-series discarded. "Other" referred to the CPR data (Sahfos) except * Capuzzo Com. Pers.

Group	ICES SSA	ICES Advice	SMS	IBTS	Benthos	Other
Blue whiting	√			X		
Catfish (Wolf-fish)				√		
Carnivorous zooplankton						√
Cod (adult)	√		X			
Cod (juvenile 0–2)	√		X	X		
Dab				√		
Diving seabirds		√	X			
Dragonets				√		
Epifaunal macrobenthos					√	
Flounder				√		
Gurnards			√	X		
Haddock (adult)	√		X			
Haddock (juvenile 0–1)	√		X	X		
Hake			√			
Halibut				√		
Herbivorous & omnivorous zooplankton						√
Herring (adult)	√		X			
Herring (juvenile 0–1)	√		X	X		
Horse mackerel	√		X	X		
Infaunal macrobenthos					√	
Large demersal fish				√		
Large piscivorous sharks				√		
Lemon sole				√		
Long-rough dab				√		

Group	ICES SSA	ICES Advice	SMS	IBTS	Benthos	Other
Mackerel	√		X			
Megrim				√		
Meiofauna					√	
Miscellaneous filter feeding pelagic fish				√		
Monkfish				√		
Nephrops	√		X	X		
Norway pout	√		X	X		
Other gadoids (large)				√		
Other gadoids (small)				√		
Plaice	√		X	X		
Saithe (adult)	√		X			
Primary production						√*
Saithe (juvenile 0–3)	√		X	X		
Sandeels	√		X	X		
Seals		√	X			
Sessile epifauna					√	
Shrimp		√				
Skate & cuckoo ray				√		
Small demersal fish				√		
Small infauna					√	
Small mobile epifauna					√	
Small sharks				√		
Sole	√		X	X		
Sprat	√		X	X		
Spurdog				√		
Squid & cuttlefish		√				
Starry ray & others			√	X		

Group	ICES SSA	ICES Advice	SMS	IBTS	Benthos	Other
Surface-feeding seabirds		√	X			
Thornback & Spotted ray				√		
Toothed whales			√			
Turbot	√			X		
Whiting (adult)	√		X			
Whiting (juvenile 0–1)	√		X	X		
Witch				√		

Table 4.3. Choice of the catch/landings time-series used for model fitting for each functional group. Cell open: time-series available, cell shaded: time-series unavailable, √: time-series selected, X: time-series discarded. SSA – C : Single species assessment – catch (1), SSA – L: Single species assessment – Landings (2), SMS – C: Multispecies assessment SMS – Catch (3) and ICES – L: ICES catch statistics – Landings (4).

Group	SSA – C	SSA – L	SMS - C	ICES – L
Baleen whales				√
Blue whiting	√	X		X
Catfish (Wolf-fish)				√
Cod (adult)	√	X	X	X
Cod (juvenile 0–2)				
Dab				(zero weight – not fitted to because not representative
Dragonets				
Flounder				(zero weight – not fitted to because not representative
Gurnards				(zero weight – not fitted to because not representative
Haddock (adult)	√	X	X	X
Haddock (juvenile 0–1)				
Hake				√
Halibut				√

Group	SSA – C	SSA – L	SMS - C	ICES – L
Herring (adult)	√	X	X	X
Herring (juvenile 0–1)				
Horse mackerel		√		X
Large demersal fish				√
Large piscivorous sharks				√
Lemon sole				√
Long-rough dab				√
Mackerel	√	X		X
Megrim				√
Miscellaneous filter feeding pelagic fish				√
Monkfish				√
Nephrops		√		X
Norway pout		√	X	X
Other gadoids (large)				√
Other gadoids (small)				√
Plaice	√	X	X	X
Saithe (adult)	√	X	X	X
Saithe (juvenile 0–3)				
Sandeels		√	X	X
Seals				
Shrimp		√		X
Skate & cuckoo ray				√
Small demersal fish				√
Small sharks				√
Sole	√	X	X	X
Sprat		√	X	X
Spurdog				√ note: zero quota species so trend may be misleading in recent years.

Group	SSA – C	SSA – L	SMS - C	ICES – L
Squid & cuttlefish				√
Starry ray & others				√
Thornback & Spotted ray				√
Toothed whales				
Turbot		√	X	X
Whiting (adult)	√	X	X	X
Whiting (juvenile 0–1)				
Witch				√

4.1.2. Time-series weighting

To determine weighting factors for the many time-series provided for the EwE model we performed a signal to noise ratio assessment for each series. The signal was fitted using a "LOcally weighted Scatterplot Smoothing" (LOESS) with the degree of smoothing required given by the optimal span determined from the bias-corrected Akaike information criterion (AICc) following the method of Hurvich and Tsai (1998). The noise was determined from the variance of the model residuals (var_{res}) and weights for EwE were determined from the inverse of the variance ($1 / var_{res}$). Figure 4.3.

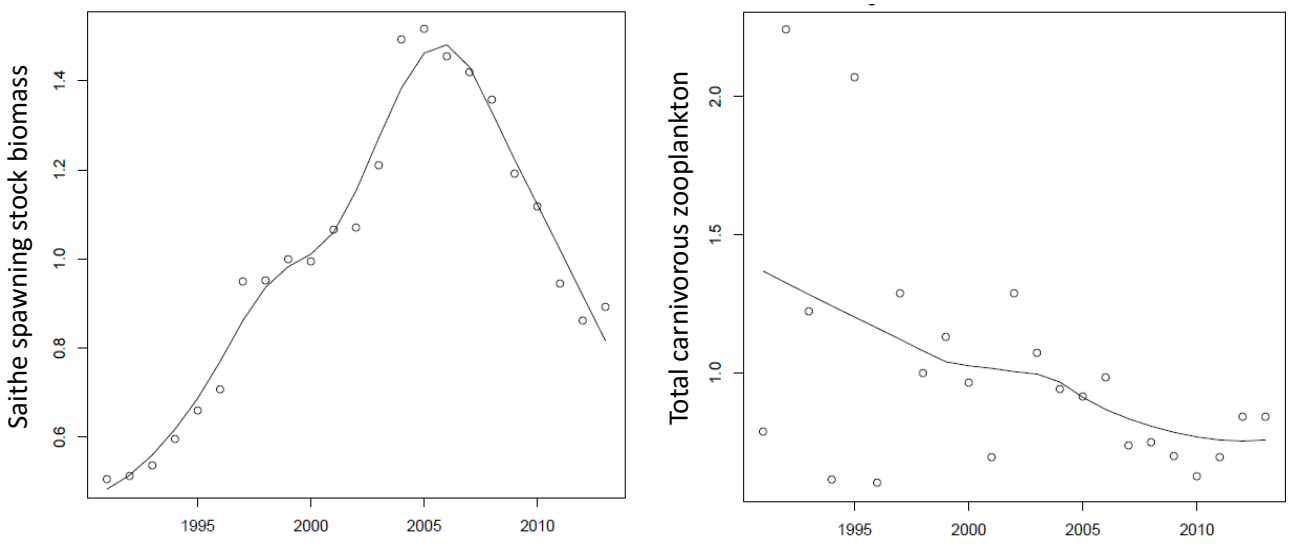


Figure 4.3. Example of high (left, weight = 2.59) and low (right, weight = 0.93) ranking time-series.

4.1.3. Stock recruitment

Table 4.4. Multi-stanza parameters

Multi-stanza name	Cod	Whiting	Haddock	Saithe	Herring
Vbert K (Nsea)	0.23	0.32	0.19	0.07	0.46
Recruit power	1	1	1	1	1
BA/B	0	0	0	0	0
Age at maturity (Nsea)	3.5	1.5	2.5	4.5	2
Wmat (g) (Nsea)	3000	125	300	700	137
or Wmax (North Sea) from surveys used as Winf (g)	15000	325	2000	20000	265
Wmat/Winf	0.20	0.38	0.15	0.035	0.52
Ref	WGNSSK15	WGNSSK15	WGNNSK 15	WGNNSK 15	HAWG 2015

It is difficult to compare the SR relationships from the EwE model with single species predictions because in addition to fishing effects, the dynamics of the adult juvenile groups are affected by the environmental forcing function. The closest we can get is to turn off all the environmental forcing functions and apply a 'V' shaped fishing pattern simultaneously to the all the multi-stanza groups by combining individual 'V'-shaped mortality patterns designed to drive the stocks biomass through high and low values. The emergent SR patterns are dependent upon both the effects of the fishing pattern and the multispecies interactions that result from them. They provide at least some indication of the how recruitment changes as adult biomass changes in the model. The parameterisation of this key run leads to stock-recruitment trajectories (under the V fishing) for cod, saithe, herring and haddock that are relatively flat over a large range of biomass. For cod, when biomass reduces from its peak, recruitment initially increases then drops very sharply at some 'critically low' stock biomass. Whiting recruitment is more dome shaped. Figure 4.4.

Single species models recruitment data indicate that the order of the relative compensation in recruitment (the relative steepness of the 50th percentile R/SSB) is saithe, cod, whiting, herring, haddock (Figure 4.5). The EwE model predicts cod, saithe, haddock, herring, whiting.

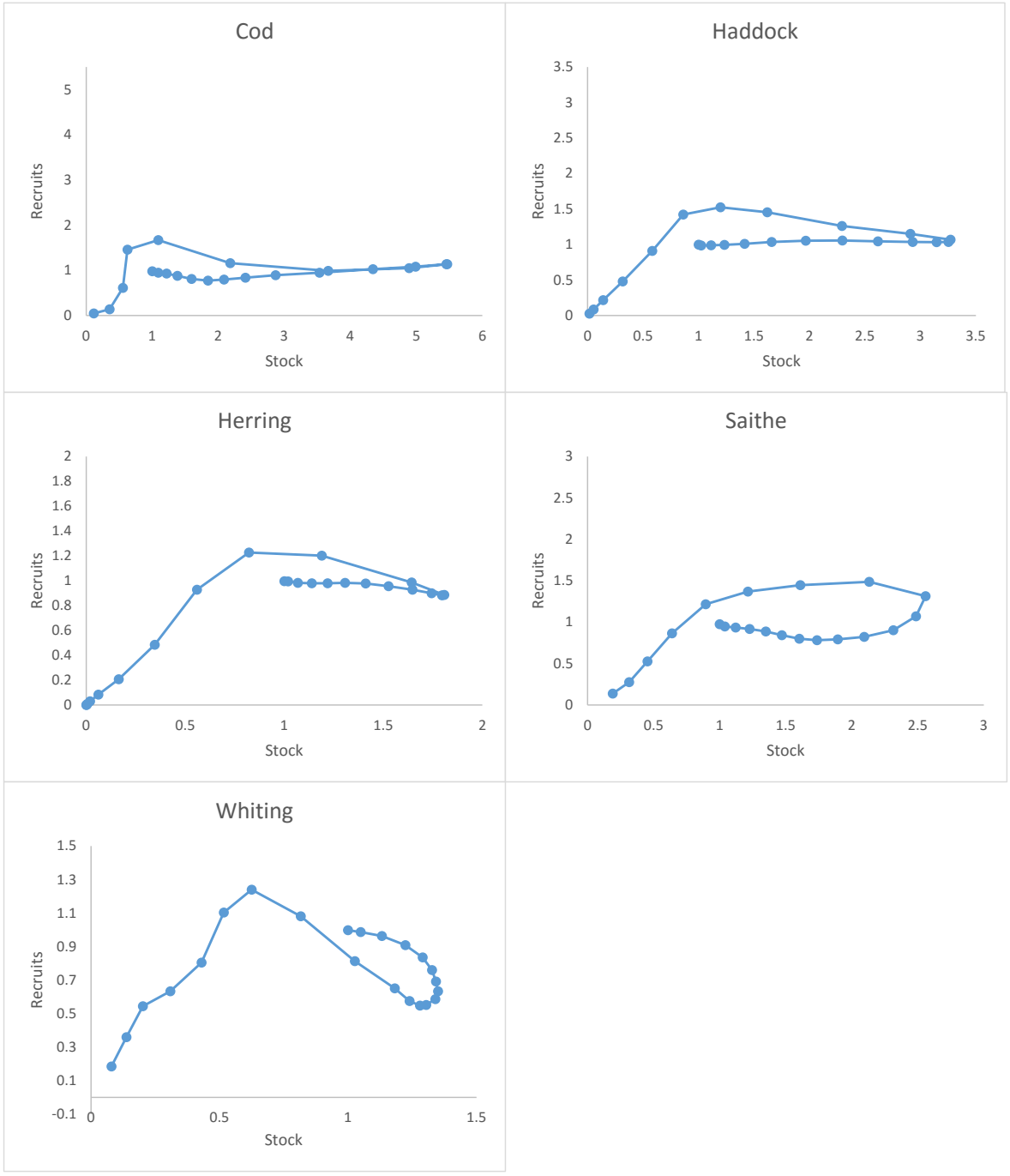


Figure 4.4. Stock recruitment trajectories under a 'V' shaped fishing regime for all multistanza groups.

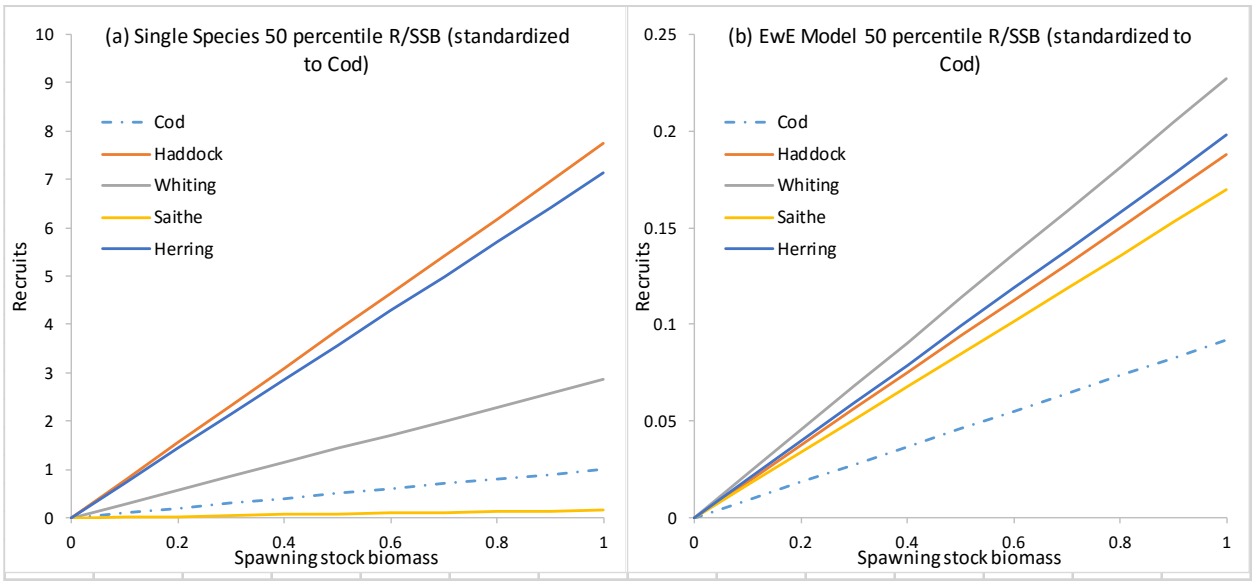


Figure 4.5. Comparison of single species and EwE Key run prediction of the relative compensation in recruitment for modelled multistanza groups.

4.1.4. Vulnerability parameters

Table 4.6. Vulnerabilities applied to specific groups in the Key Run. All other vulnerabilities were set at the default value of 2.

Group #	Group name	Vulnerability
10	Starry ray + others	1.31
13	Cod (juvenile 0–2)	2
14	Cod (adult)	5
15	Whiting (juvenile 0–1)	3
16	Whiting (adult)	5
17	Haddock (juvenile 0–1)	2.5
18	Haddock (adult)	4
19	Saithe (juvenile 0–3)	2
20	Saithe (adult)	2.1
21	Hake	3
22	Blue whiting	4
23	Norway pout	3.32
28	Herring (juvenile 0–1)	2
29	Herring (adult)	10
30	Sprat	5
31	Mackerel	4
32	Horse mackerel	5.5

33	Sandeels	5
34	Plaice	4
38	Sole	10
41	Turbot	3.35
51	Carnivorous zooplankton	1.1
52	Herbivorous & Omnivorous zooplankton (copepods)	100
55	Nephrops	10
58	Shrimp	2.45

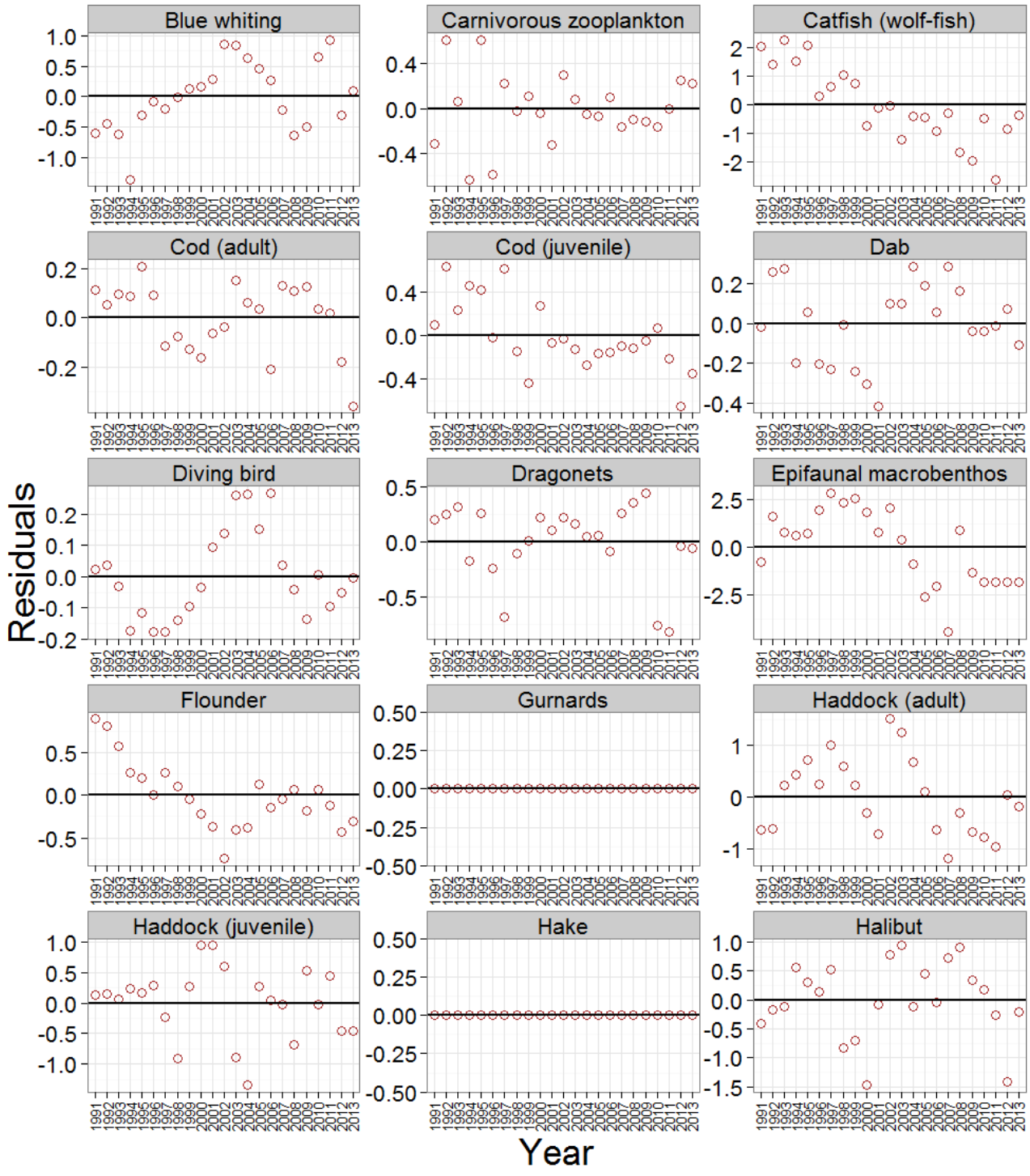
4.2. Fitting diagnostics and performance

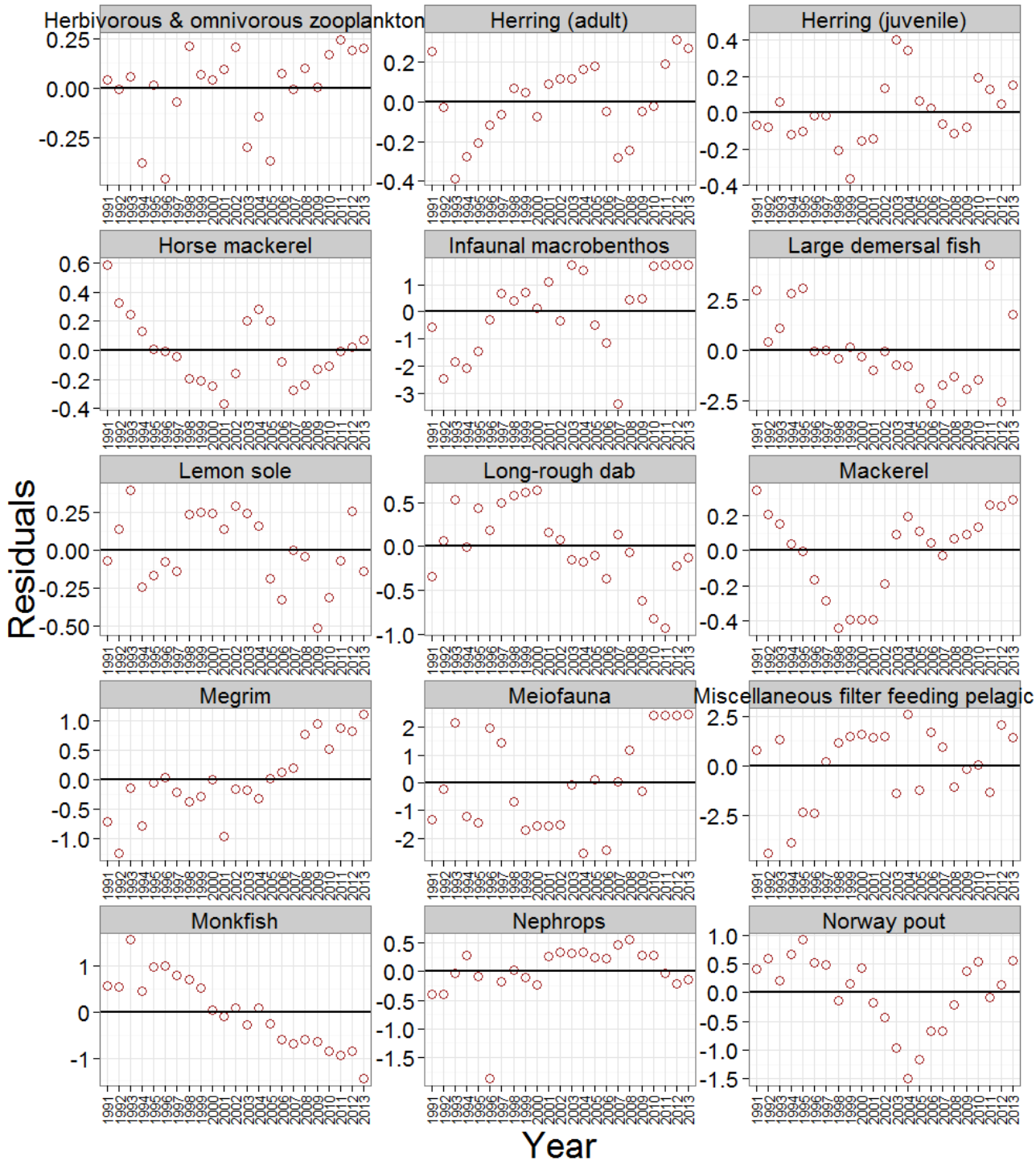
Plots of sum of squares residuals of model predictions to observation data are given in Figures 4.9, 4.10 for key species of interest, including all those for which vulnerability was estimated during model fitting. The rank order of SS values contributing to the total SS (Table 4.7), shows that the key species of interest in the model fitting score high in the ranking (where low SS score rank highly). This demonstrates that good model fits are achieved for these data, and that fitting data for the juvenile groups is more difficult due to their high variability. Table 4.8 provides a qualitative summary of the key run fits to data.

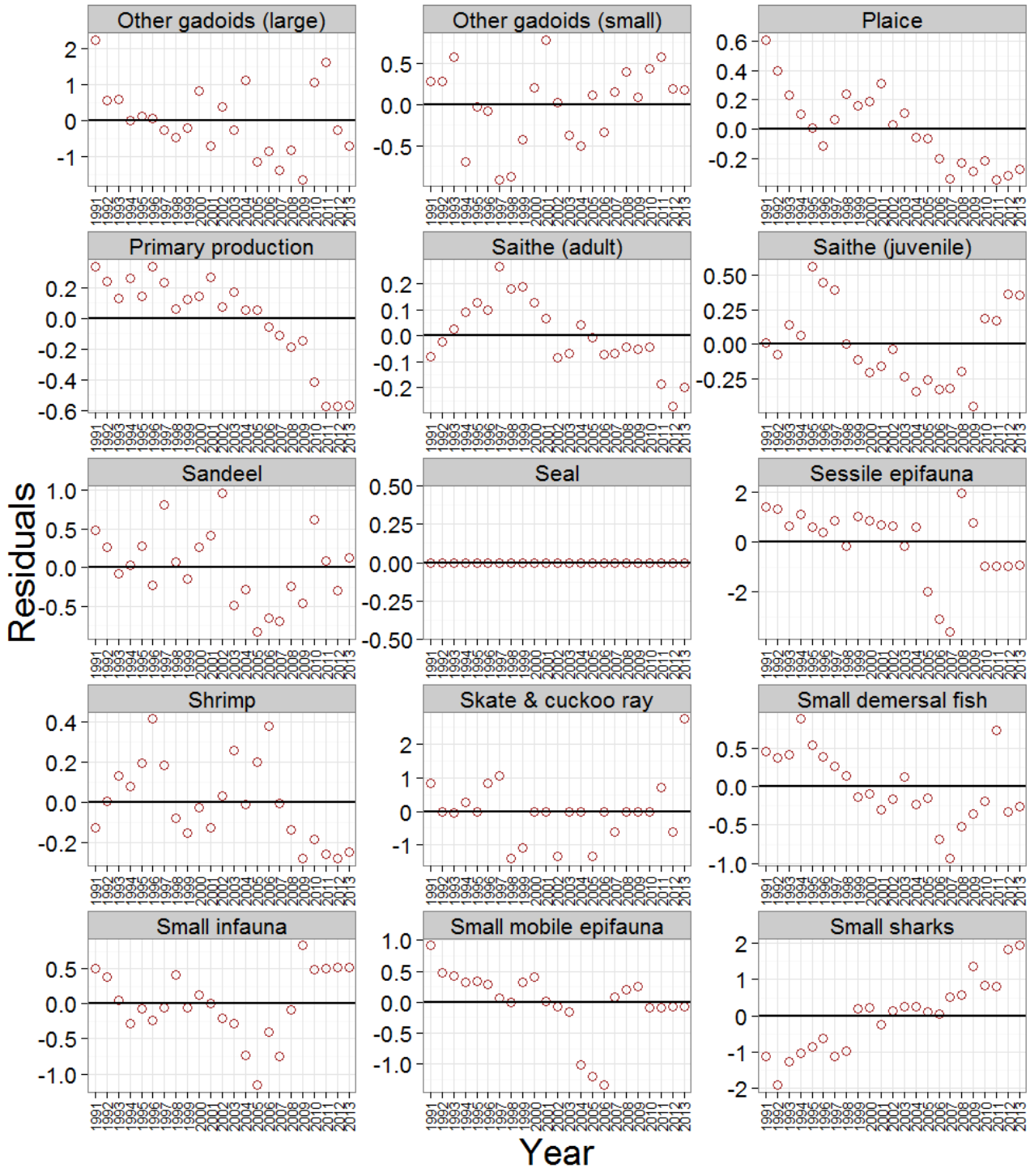
Table 4.7. Rank order sums of squares contributions of each functional group to the overall model fit. Small values indicate good fits to data – i.e. a low contribution to the overall difference between predicted and observed.

	Prey \ predator	SS biomass
14	Cod (adult)	0.43
20	Saithe (adult)	0.43
65	Diving seabirds	0.44
28	Herring (juvenile 0–1)	0.67
4	Surface-feeding seabirds	0.82
29	Herring (adult)	0.83
35	Dab	0.87
52	Herbivorous & Omnivorous zooplankton (copepods)	0.88
58	Shrimp	0.91
32	Horse mackerel	1.19
38	Sole	1.21
39	Lemon sole	1.25
31	Mackerel	1.34
34	Plaice	1.47

41	Turbot	1.57
66	Phytoplankton	1.80
19	Saithe (juvenile 0–3)	1.83
10	Starry ray + others	1.97
51	Carnivorous zooplankton	2.05
13	Cod (juvenile 0–2)	2.32
44	Dragonets	2.65
37	Flounder	3.43
30	Sprat	3.52
36	Long-rough dab	4.22
47	Small demersal fish	4.61
16	Whiting (adult)	4.65
25	Other gadoids (small)	4.75
33	Sandeels	4.99
60	Small infauna (polychaetes)	5.20
55	Nephrops	5.25
59	Small mobile epifauna (swarming crustaceans)	6.26
22	Blue whiting	7.26
17	Haddock (juvenile 0–1)	7.31
42	Megrim	7.99
43	Halibut	9.64
23	Norway pout	9.68
40	Witch	10.25
18	Haddock (adult)	11.83
26	Monkfish	12.90
6	Spurdog	13.47
11	Thornback & Spotted ray	15.10
15	Whiting (juvenile 0–1)	16.68
12	Skate + cuckoo ray	18.09
24	Other gadoids (large)	19.63
49	Squid & cuttlefish	21.37
8	Small sharks	21.87
45	Catfish (Wolf-fish)	38.03
61	Sessile epifauna	44.47
57	Infaunal macrobenthos	48.88
62	Meiofauna	64.60
46	Large demersal fish	77.67
48	Miscellaneous filterfeeding pelagic fish	82.09
56	Epifaunal macrobenthos (mobile grazers)	85.01
	TOTAL	**717.64**


Blue whiting
Carnivorous zooplankton
Catfish (wolf-fish)
Cod (adult)
Cod (juvenile)
Dab
Diving bird
Dragonets
Epifaunal macrobenthos
Flounder
Gurnards
Haddock (adult)
Haddock (juvenile)
Hake
Halibut
Residuals
Year


Herbivorous & omnivorous zooplankton
Herring (adult)
Herring (juvenile)
Horse mackerel
Infaunal macrobenthos
Large demersal fish
Lemon sole
Long-rough dab
Mackerel
Megrim
Meiofauna
Miscellaneous filter feeding pelagic
Monkfish
Nephrops
Norway pout
Residuals
Year


Other gadoids (large)
Other gadoids (small)
Plaice
Primary production
Saithe (adult)
Saithe (juvenile)
Sandeel
Seal
Sessile epifauna
Shrimp
Skate & cuckoo ray
Small demersal fish
Small infauna
Small mobile epifauna
Small sharks
Residuals
Year

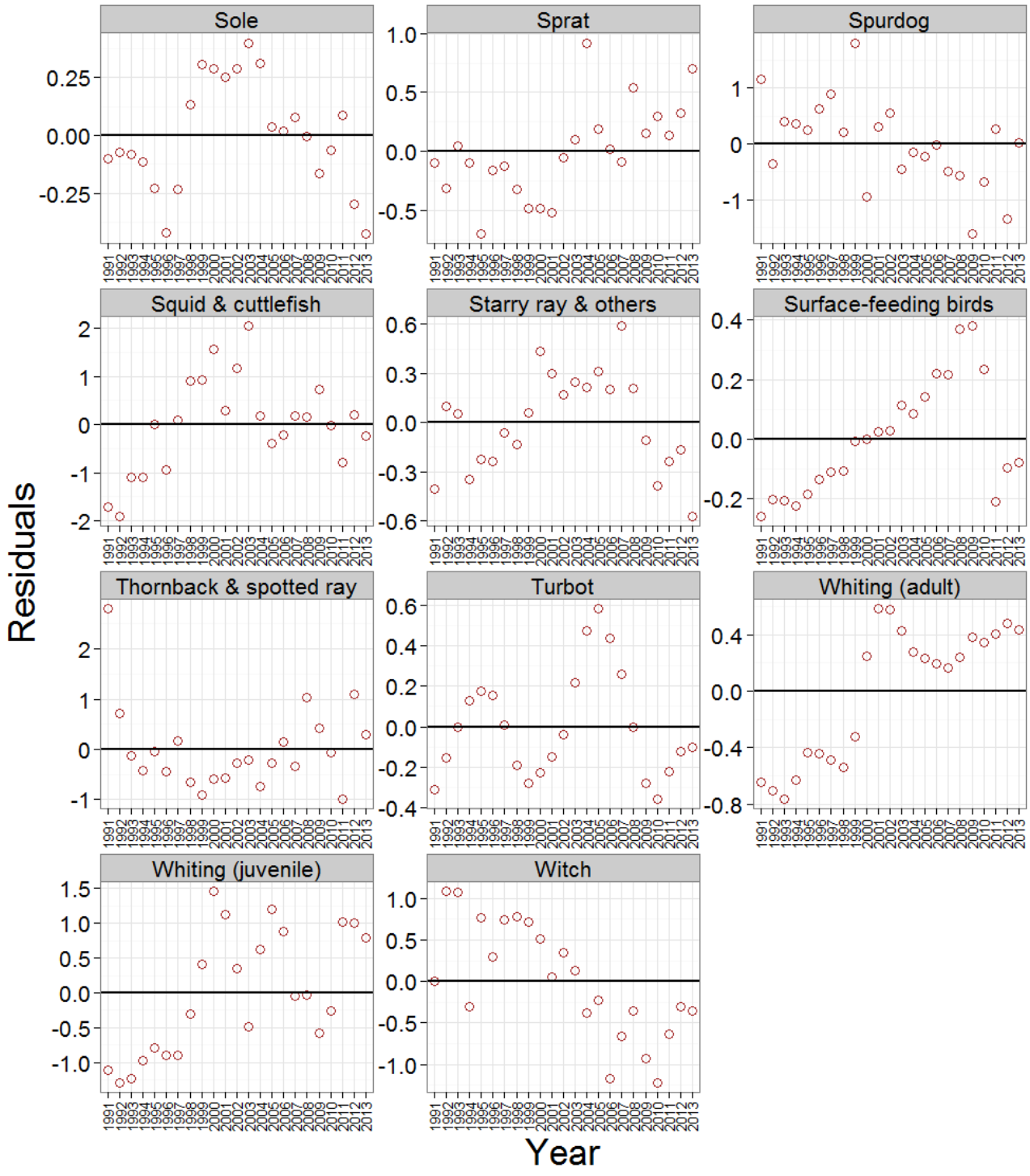
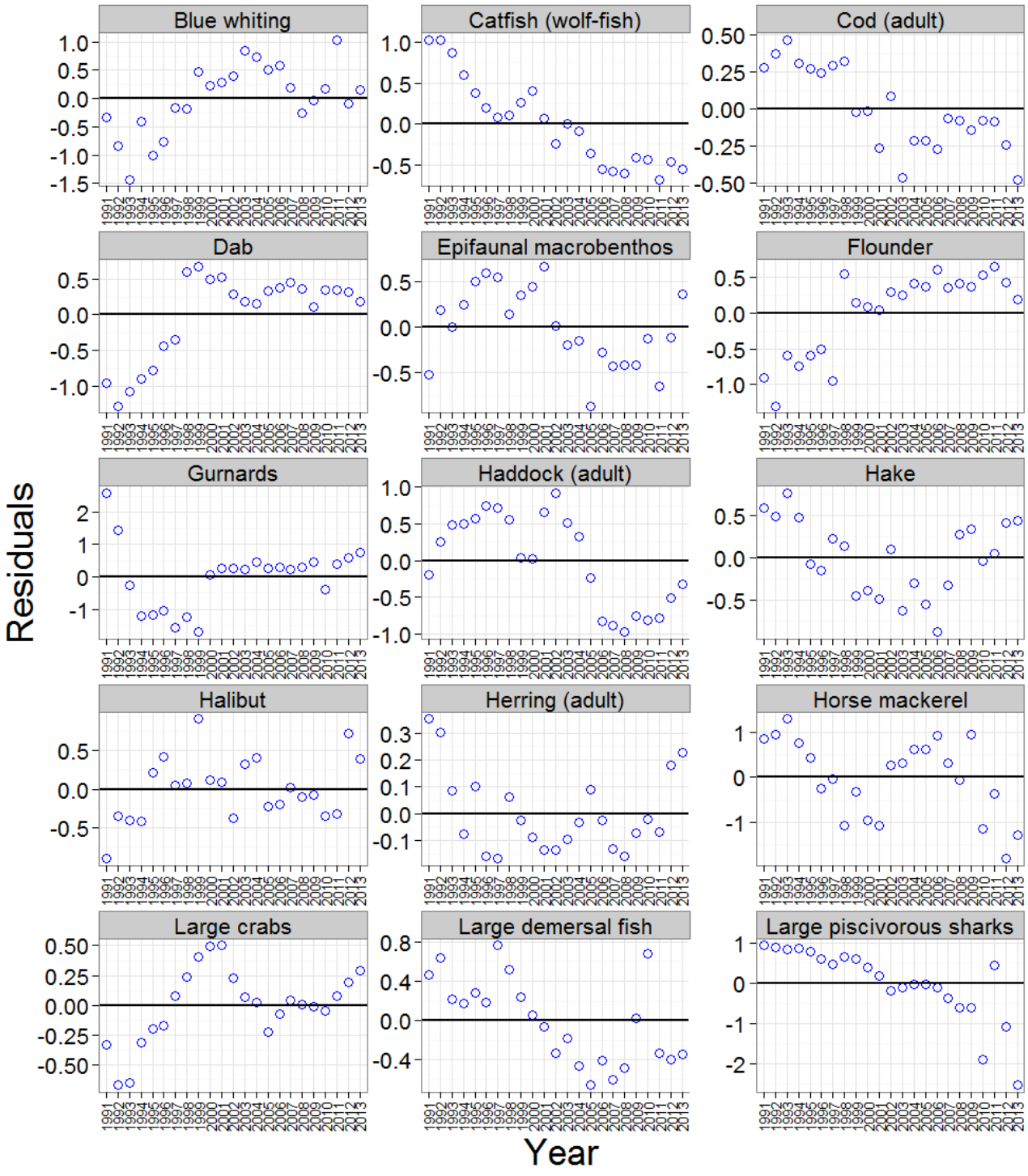
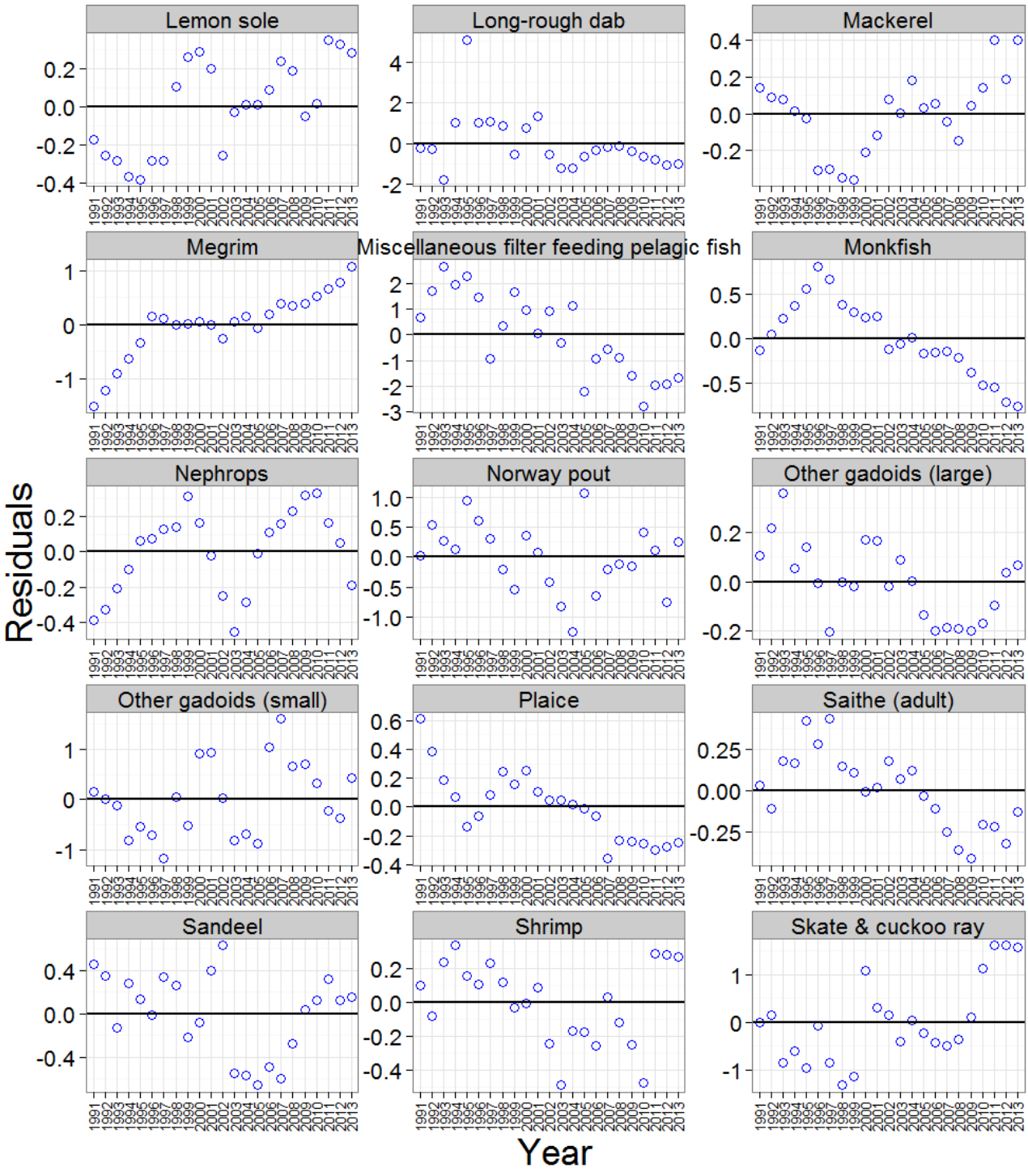


Figure 4.9. Residuals for relative biomass plots.


Blue whiting
Catfish (wolf-fish)
Cod (adult)
Dab
Epifaunal macrobenthos
Flounder
Gurnards
Haddock (adult)
Hake
Halibut
Herring (adult)
Horse mackerel
Large crabs
Large demersal fish
Large piscivorous sharks
Residuals
Year


Lemon sole
Long-rough dab
Mackerel
Megrim
Miscellaneous filter feeding pelagic fish
Monkfish
Nephrops
Norway pout
Other gadoids (large)
Other gadoids (small)
Plaice
Saithe (adult)
Sandeel
Shrimp
Skate & cuckoo ray
Residuals
Year

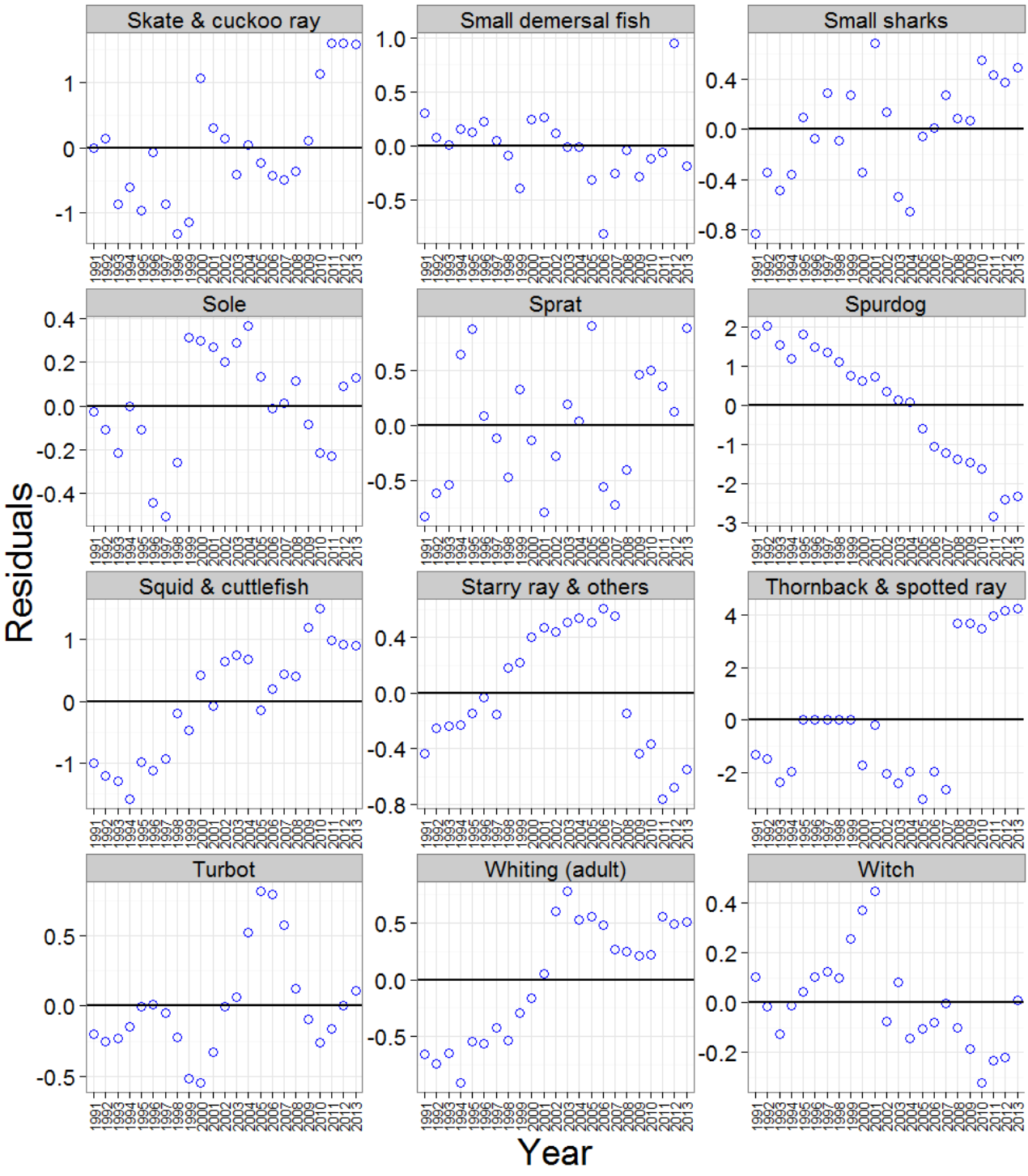


Figure 4.10. Residuals for catch plots.

Table 4.8. Qualitative assessment of the performance of the model fits (see Figures 5.1 to 5.4).

GROUP NAME	B. TREND	B. MAGNITUDE	C. TREND	C. MAGNITUDE
Blue whiting	Medium	Good	Medium	Medium
Carnivorous zooplankton	Medium	Good	NA	NA
Catfish (Wolf-fish)	Poor	Good	Medium	Poor
Cod (adult)	Good	Good	Good	Good
Dab	Poor	Good	Poor	Poor
Diving seabirds	Poor	Good	NA	NA
Dragonets	Medium	Good	NA	NA
Epifaunal macrobenthos	Poor	Good	Medium	Medium
Flounder	Poor	Good	Poor	Poor
Gurnards	NA	NA	Poor	Medium
Haddock (adult)	Medium	Good	Poor	Medium
Hake	NA	NA	Good	Good
Halibut	Poor	Good	Medium	Medium
Herbivorous & Omnivorous zooplankton	Medium	Good	NA	NA
Herring (adult)	Good	Good	Good	Good
Horse mackerel	Good	Good	Medium	Good
Infaunal macrobenthos	Poor	Good	Poor	Poor
Large crabs	NA	NA	Medium	Good
Large demersal fish	Poor	Good	Medium	Poor
Large piscivorous sharks	NA	NA	Poor	Medium
Lemon sole	Poor	Good	Good	Good
Long-rough dab	Poor	Good	Poor	Poor
Mackerel	Good	Good	Good	Medium
Megrim	Poor	Good	Poor	Poor
Miscellaneous filterfeeding pelagic fish	Poor	Good	Good	Medium
Monkfish	Poor	Good	Poor	Good
Nephrops	Poor	Good	Good	Medium
Norway pout	Poor	Good	Good	Medium
Other gadoids (large)	Poor	Good	Good	Good
Other gadoids (small)	Poor	Good	Poor	Poor
Plaice	Good	Good	Medium	Poor
Saithe (adult)	Good	Good	Poor	Poor
Sandeels	Good	Good	Medium	Poor
Seals	NA	NA	NA	NA
Sessile epifauna	Poor	Good	Poor	Poor
Shrimp	Good	Good	Poor	Poor
Skate + cuckoo ray	Poor	Good	Poor	Poor
Small demersal fish	Poor	Good	Poor	Poor
Small infauna (polychaetes)	Poor	Good	NA	NA
Small mobile epifauna	Poor	Good	NA	NA

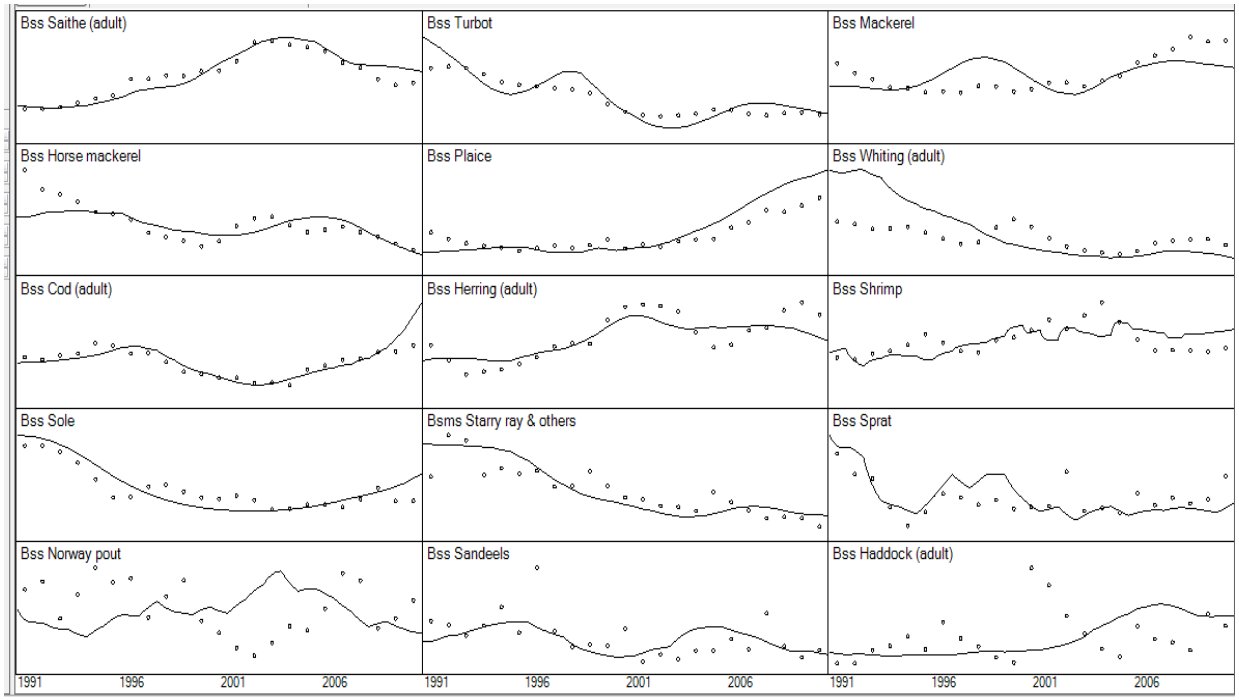
GROUP NAME	B. TREND	B. MAGNITUDE	C. TREND	C. MAGNITUDE
Small sharks	Poor	Good	Poor	Medium
Sole	Good	Good	Good	Good
Sprat	Good	Good	Good	Good
Spurdog	Poor	Good	Poor	Medium
Squid & cuttlefish	Medium	Good	Poor	Medium
Starry ray + others	Good	Good	Good	Good
Thornback & Spotted ray	Good	Good	Poor	Poor
Turbot and brill	Good	Good	Good	Medium
Whiting (adult)	Medium	Good	Good	Good
Witch	Poor	Good	Good	Poor

4.2.1. Comparison of the 'Pretty' fit versus the Key Run

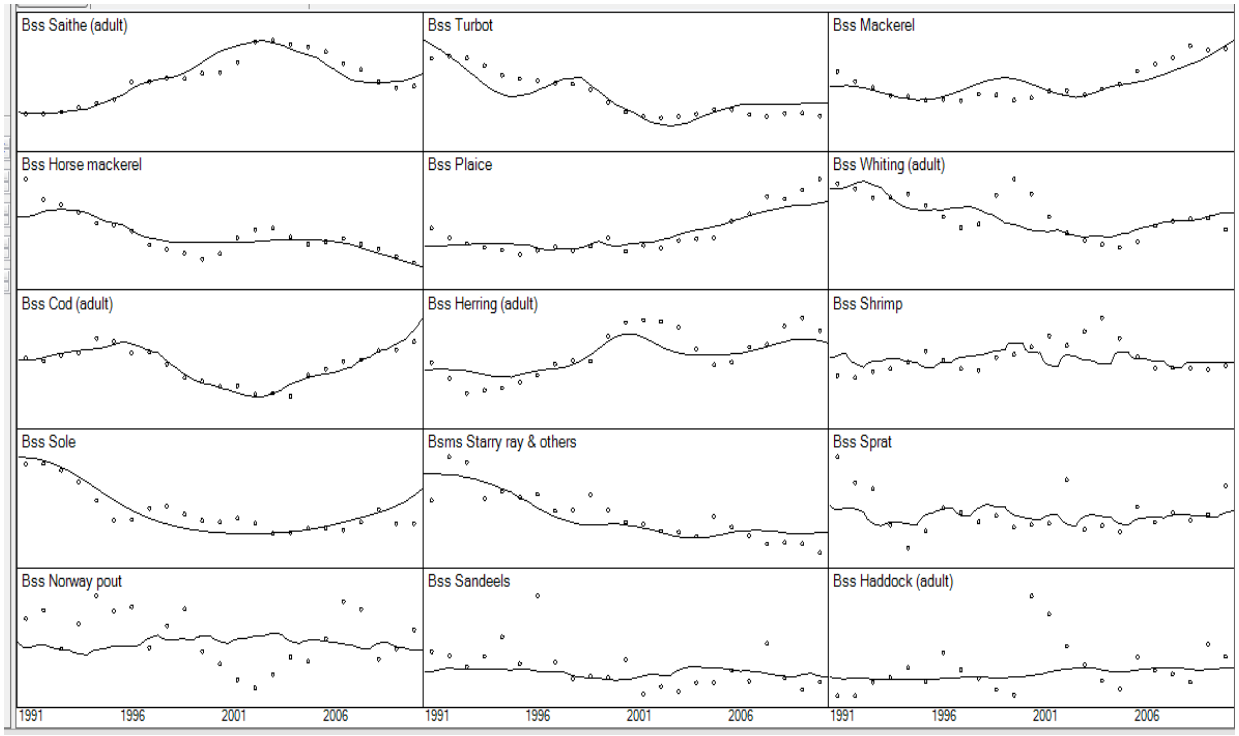
(see point 17, section 4.1)

Comparison of the 'Pretty' model fit achieved by applying the vulnerabilities estimated by the fitting routine, with those obtained when considerations of credible model behaviour are taken in to account to produce the Key Run (Figures 4.11 and 4.12).

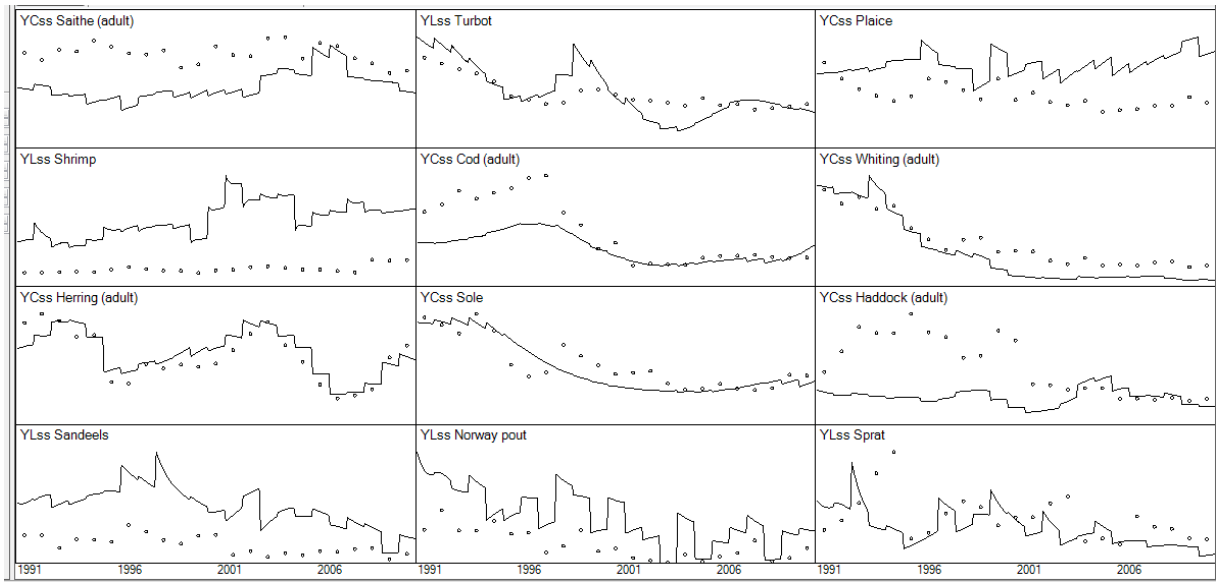
Key Run Biomass



'Pretty fit' biomass



Key Run catches



Pretty fit catches

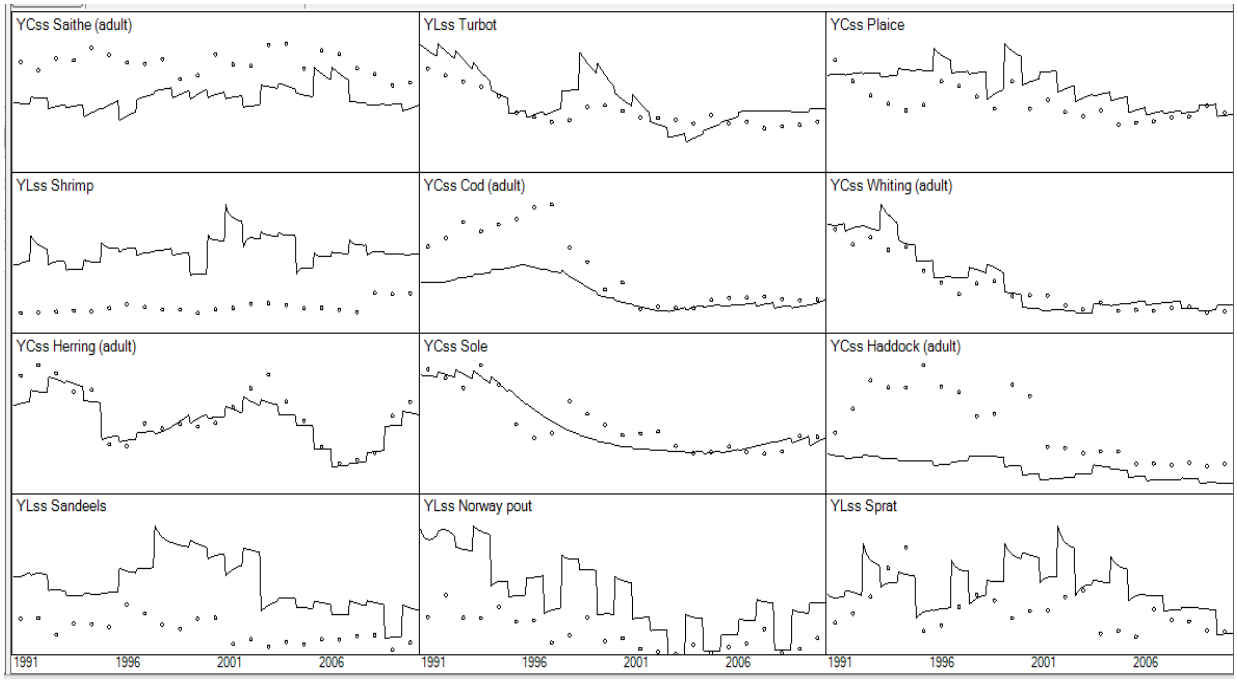


Figure 4.11. Comparison of selected biomass (upper pair) and catch fit (lower pair) plots for the Key Run and Pretty Fit parametetisations.

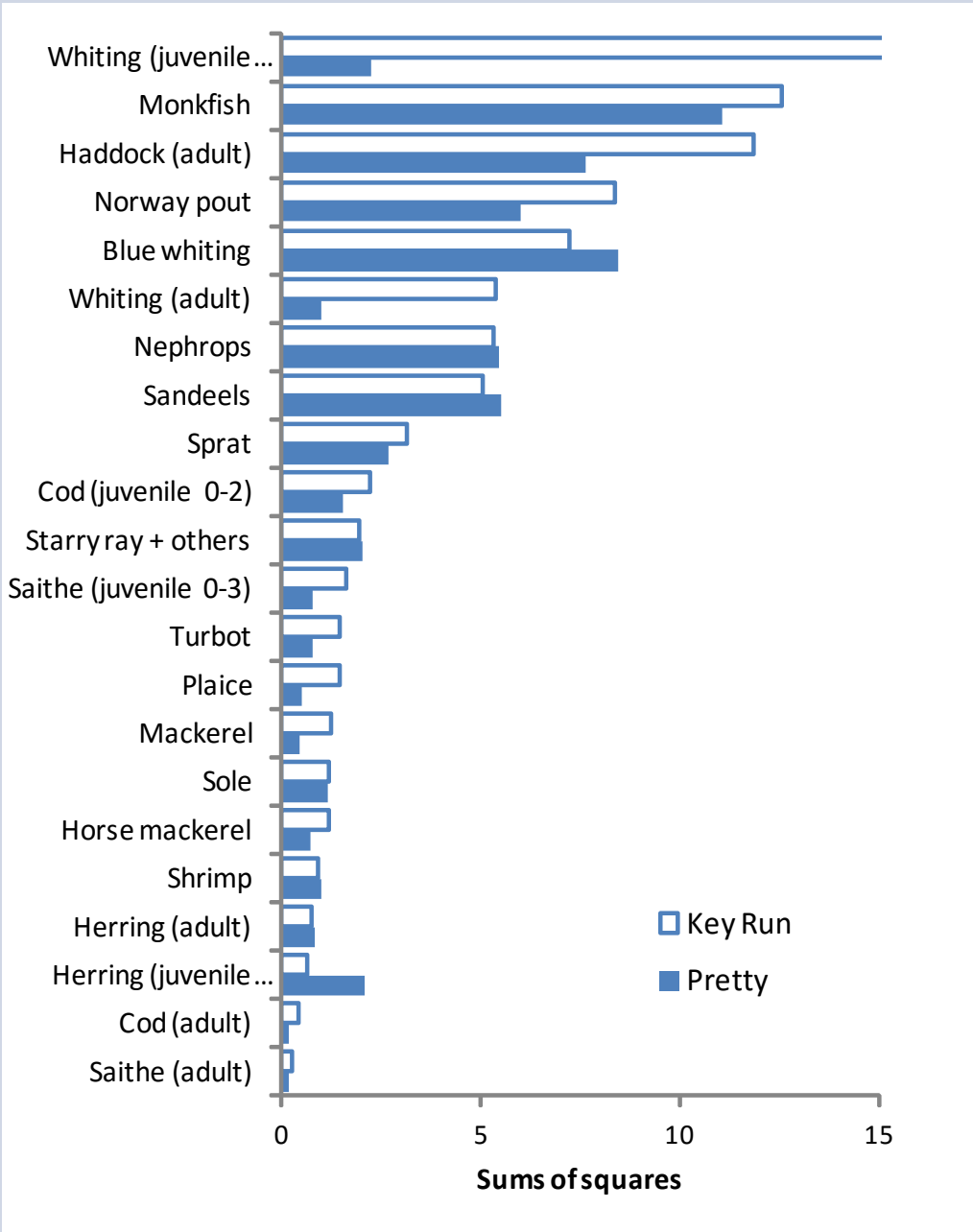


Figure 4.12. Comparison of the sums of squares of the Key Run with the Pretty fit.

4.3. Comments on quality of the key run

During the review of the Key Run by ICES WGSAM several important issues were discussed that warrant being noted in relation to confidence in interpretation of the key run outputs, application of the model in evaluating research and management questions and considerations for future key runs.

- The fits to catch data for non-assessed species are quite poor, raising the question whether it's a good idea to fit to the landings of non-assessed species. In many cases there is not an easy answer because it is difficult to disentangle the poor fit from the poor quality of the catch data, particularly in relation to the non-assessed species. We know that the landings data for some species is not representative of what is caught. During the review the decision was set the data weighting for the landings of dab, flounder and gurnard to zero, thereby excluding their influence on the fit. Landings data for some other species are also problematic. For example, spurdog (a zero TAC species since 2010 and restrictive management since 2006), where more recent estimates might be unreliable, and for skates and rays the landings time-series is often problematic due to changes in the species reporting categories. Issues with potentially high discard rates can also mean that the data are unrepresentative of the true catches. In many cases of non-assessed stocks, we find that the model predicts higher catches than reported landings. This issue was also discussed this during the 2011 key run. The conclusion was that the landings data should be used (but with due caution) because we are dealing with a whole ecosystem model and including constraints at different trophic level is important. Plus while, total amounts might be unrepresentative, the trends still provide useful information. The weighting applied to the times series provides a way to less the effect of any variability in landings data on the fit, and given our awareness of the issues we can identify specific areas of concern related to any application.
- For the assessed species, where the fits to biomass are best, poor fits to catch data for some species does not necessarily indicate that the biomass fit is good for the wrong reason. For several species (cod being good example) there is strong evidence that environmental drivers seem to play a bigger role in explaining biomass trends. We suspect the poor catch fits relate both to model estimates of F and effort and also to issues with the catch data. Even though efforts are made to estimate discards, the true catches can be highly uncertain because of the high discard rates. In many cases we note that the model predicts higher catches than the observations.

- Building on the pattern-oriented approach being used to judge the quality of the model fit and its behaviour, it was proposed by the WGSAM expert review group that another useful evaluation could be to compare model estimates of unfished biomass to available estimates of unfished biomass from single species assessments and other multispecies models. It would also be of interest to examine the effect of driving the model with catches rather than F. Thus model skill could be tested against not just time-series fits and Fsmy estimates, but also the persistence of stocks when faced with historical catches or in the absence of fishing. This would be a useful test despite concerns over the quality of catch data discussed above. We have taken on board the comments about using catch data instead of F in fitting, as well as other alternatives such as increasing the weighting put on catch, or not including the catch data for non-assessed species in the fitting. This explora-

tion could be quite extensive and unfortunately, given the resources and time, it has not been possible to undertake these additional evaluations of the present Key Run.

- High P/B values in the Ecopath base model were considered to an issue leading to overly productive stocks, characterised by high Fmsy estimates and rapid rates of recovery. For example, this 'overcompensation' could explain the spike in the model prediction for cod biomass at the end of the run when fishing mortality has been much reduced. In review we looked again at estimates of Z=F+M in 1991 based on the ICES stock assessment data, and can find no justifiable reason to reduce the P/B's in the base Ecopath model. Given that these rates are used to parameterise Ecopath base 'state' and are based on the best available estimates from ICES assessments it's something we cannot escape. This type of problem holds for other models, not just EwE; future projections depend on assumption about productivity in terms of growth and recruitment. Furthermore, the high P/B values in the base year might be essential to getting a good fit in the early years, but possibly less so in later years. In an ideal situation, we could change the 'base state' for P/B and the vulnerability from year to year. Perhaps this is something to think about for EwE development? In relation to this key run, it means that at least we have awareness of the reasons why predictions for some groups might lead to overly or underly optimistic projections when, for instance, fishing is stopped in the model. For many of the species, Z has come down considerably over the last 10 years because of reductions in F and it's comforting that the comparison of key run Z estimates with the recent SMS model key run show close congruency. Furthermore, in relation to future applications, this will not be a cause for concern because our intention is to use the model using a new Management Strategy Evaluation routine that draws upon 1000's of possible parameterisations of the initial state of the Ecopath model when evaluating the impact of alternative strategies. This way the uncertainty in P/B and all the other Ecopath and Ecosim parameters will be taken account of.
- One suggestion regarding ways to address the issue that a high productivity for some groups (such as cod and haddock) was leading to high Fmsy estimates was to consider allowing non-zero biomass accumulation in a (newly rebalanced) Ecopath model. This has recently been suggested also by Ainsworth and Walters (2015), but it would involve substantial work far beyond the scope of resources presently available. The original decision not to include biomass accumulation in the base Ecopath model was based on the pragmatism of having a model whose starting point is steady state, which provides a strong reference point from which to examine the effect of disruptions in the food web. However, for some species where the biomass dynamcis show clear trends but we do not necessarily a good reason why, there might still be a good rationale for driving their dynamics by including biomass accumulation or Ecopath or through direct forcing in Ecosim. Following the review it was agreed to force the biomass dynamics of seals, hake and gurnards, which have shown large continuous changes in abundance and as top predators we know they will have an important effect on

their prey. Where at all possible our intention in establishing a Key Run model was to avoid overcomplicating the model parameterisation – using readily available data and developing a process whereby the Key Run could be updated every few years. For that reason, we feel that the detailed work required to establish a new parameterisation of Ecopath that includes biomass accumulation is better address in a specific research project.

4.4. Key run specification and setup

Table 4.9. Definition of the model setup required to reproduce the Key Run. Note: Specific details of the key-run model settings can be found in file: NSea 2015 KEY RUN Snapshot.xls.

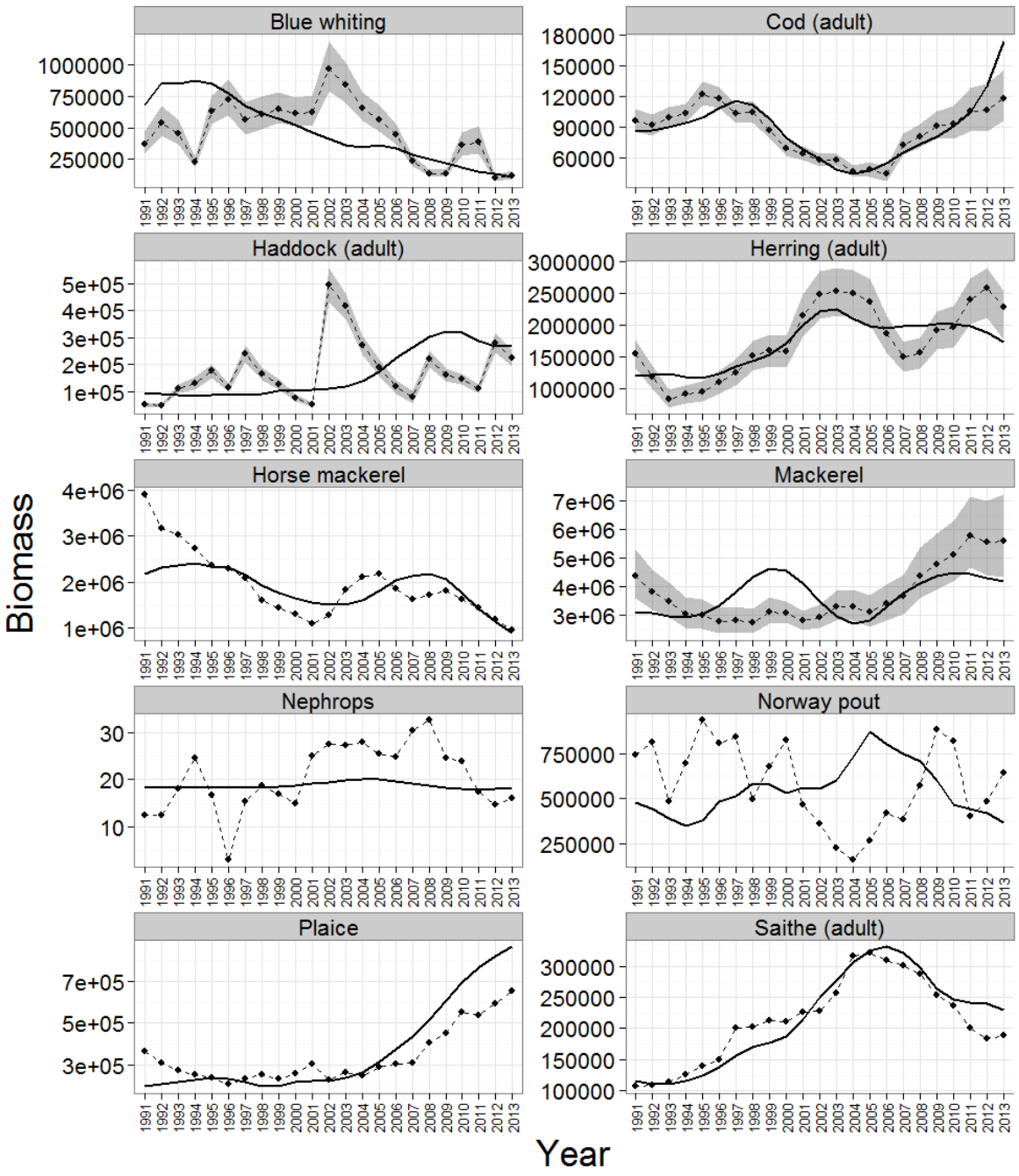
Ecopath version	Version 6.4.11414 (Compiled 10/10/14)
Database name	Keyrun 2015_NorthSea1991_12Jan16.eweaccdb
Ecopath Model name	NorthSea1991–2013 Key Run
Time-series file name	North Sea Time Serie 1991_2013_12Jan2016.csv
Ecosim scenario name	Basic setup
Fishing time-series	Yes (see report for detail)
PP force	Yes (see report for detail)
Consumer forcing	Yes (see report for detail)
Sums of squares	793.4
number of time-series fitted to	113 (3 forced time-series)

5. Key Run Outputs

5.1. Model fits to data to observed data [file: Ecosim Fits 1991–2013 Predicted and Observed.xlsx]

The fit of model predictions to observed data for selected key species of interest are shown in Figures 5.1 to 5.5.

5.1.1. Biomass


Blue whiting
Cod (adult)
Haddock (adult)
Herring (adult)
Horse mackerel
Mackerel
Nephrops
Norway pout
Plaice
Saithe (adult)
Biomass
Year

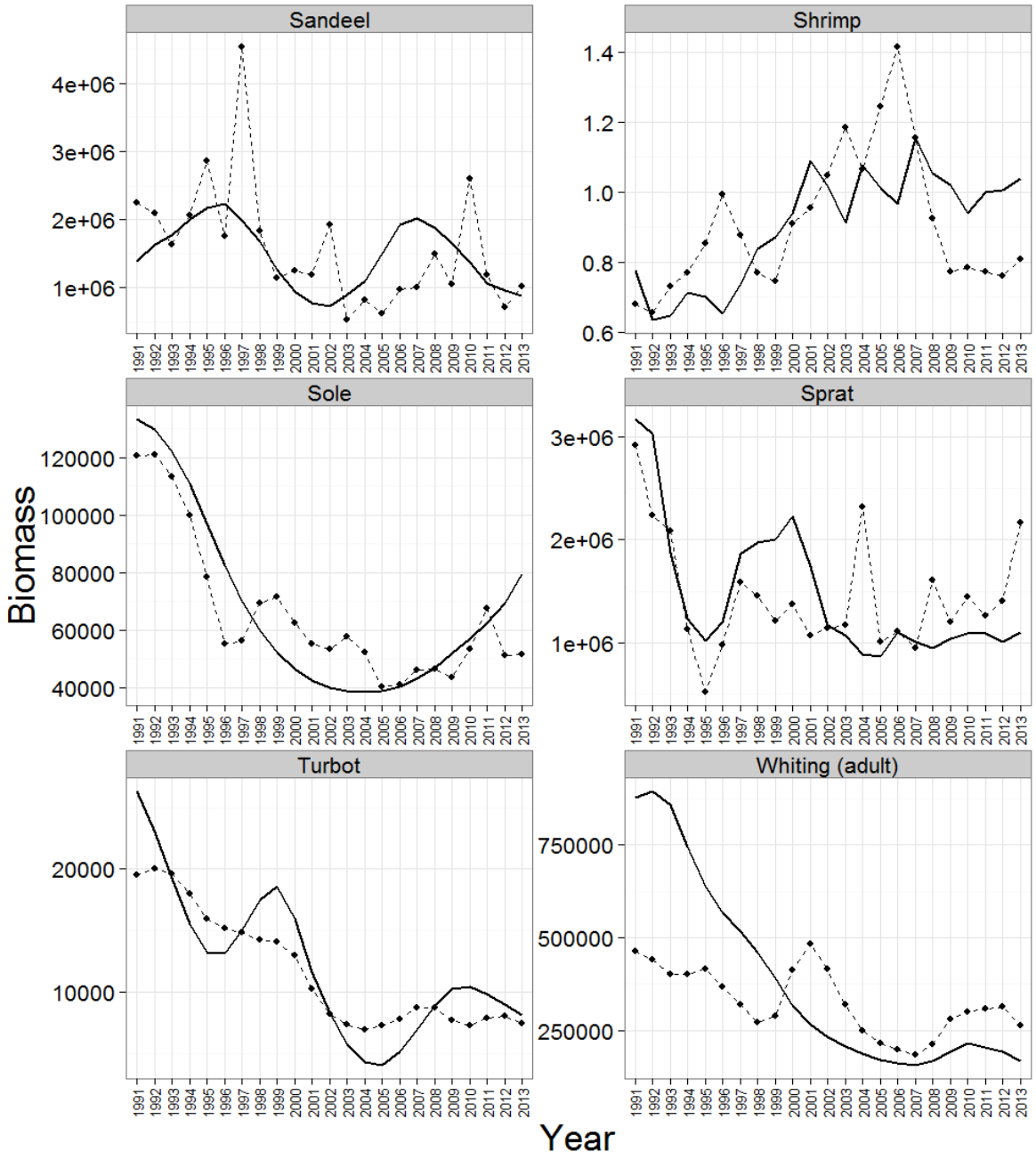
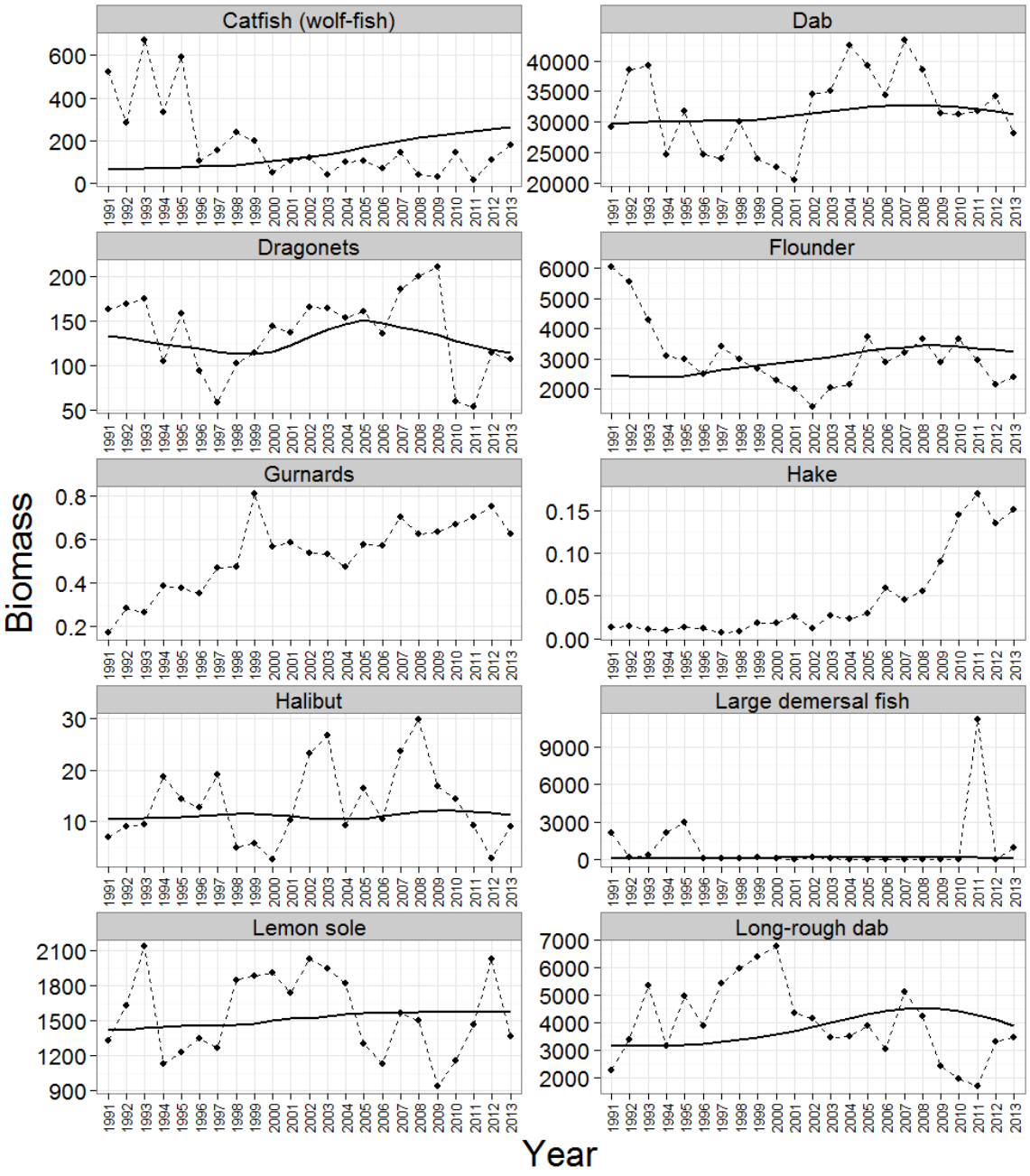
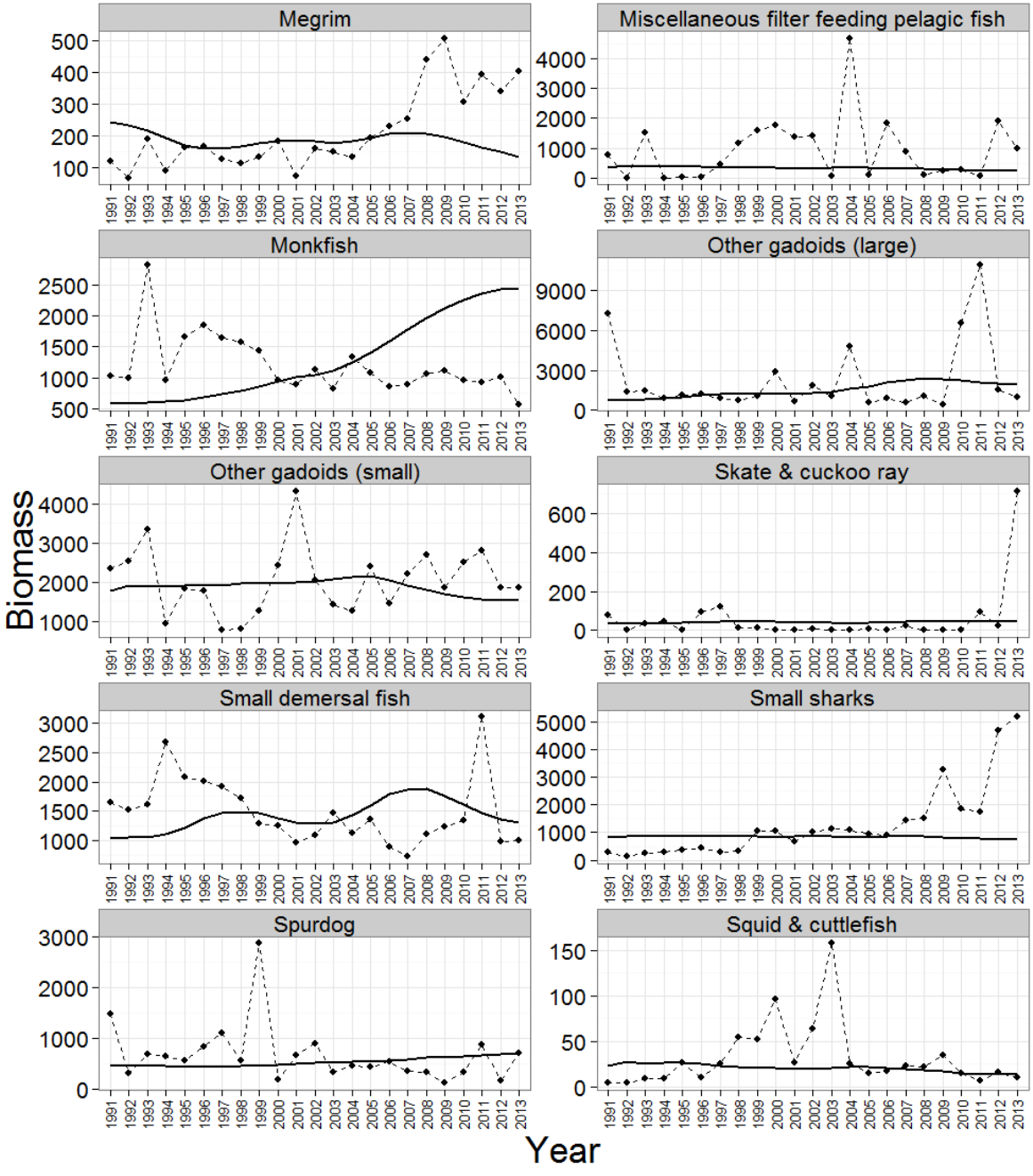
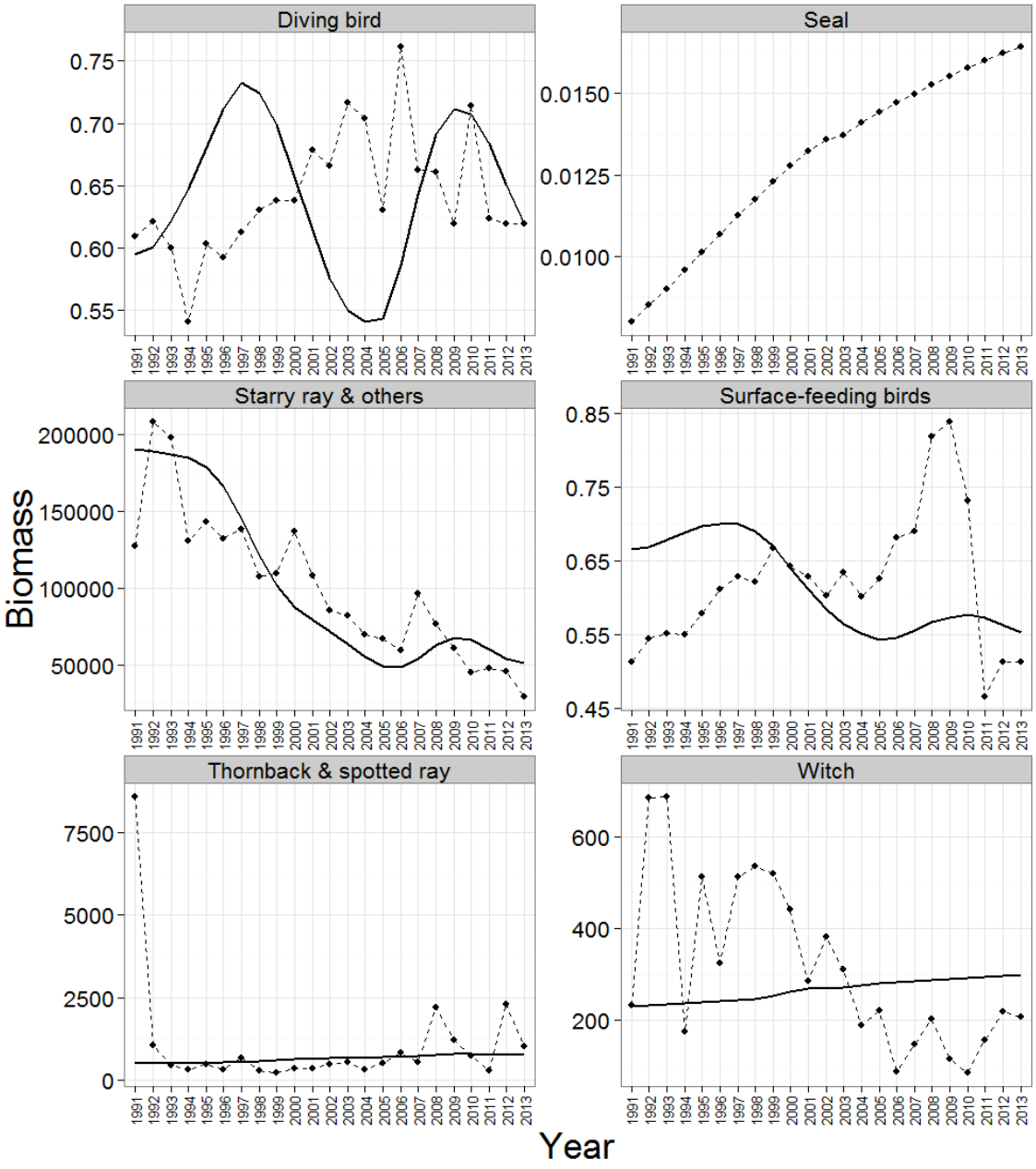


Figure 5.1 Relative biomass plots - observed and model predicted. 'Observed' data are derived from single species stock assessments, 95% confidence interval of the observed data are represented when available (grey area).


Catfish (wolf-fish)
Dab
Dragonets
Flounder
Gurnards
Hake
Halibut
Large demersal fish
Lemon sole
Long-rough dab
Biomass
Year


Megrim
Miscellaneous filter feeding pelagic fish
Monkfish
Other gadoids (large)
Other gadoids (small)
Skate & cuckoo ray
Small demersal fish
Small sharks
Spurdog
Squid & cuttlefish
Biomass
Year


Diving bird
Seal
Starry ray & others
Surface-feeding birds
Thornback & spotted ray
Witch
Biomass
Year

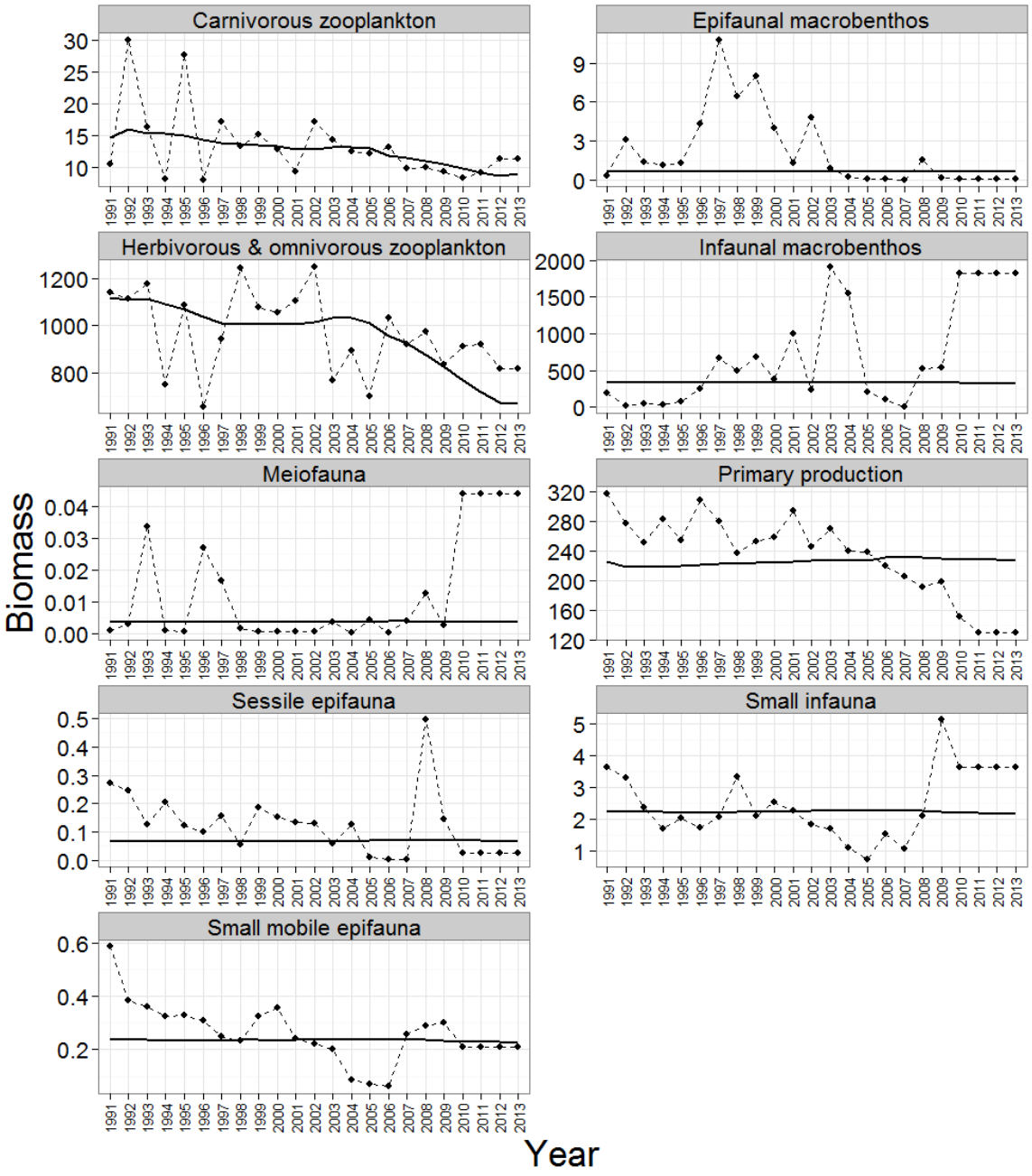
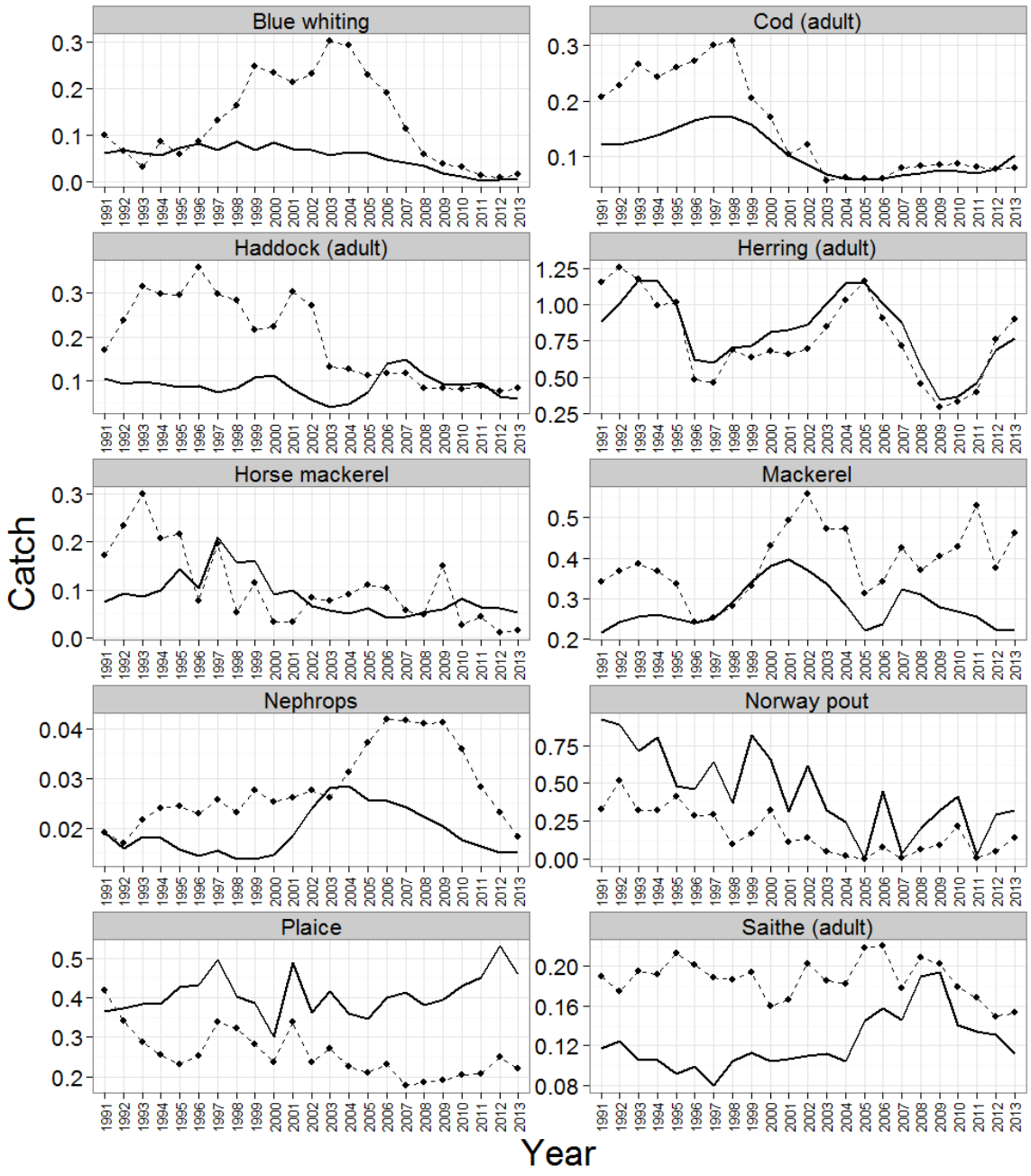


Figure 5.2 Relative biomass plots - observed and model predicted for non-assessed fish, benthos and zooplankton based on survey data.

5.1.2. Catches


Blue whiting
Cod (adult)
Haddock (adult)
Herring (adult)
Horse mackerel
Mackerel
Nephrops
Norway pout
Plaice
Saithe (adult)
Catch
Year

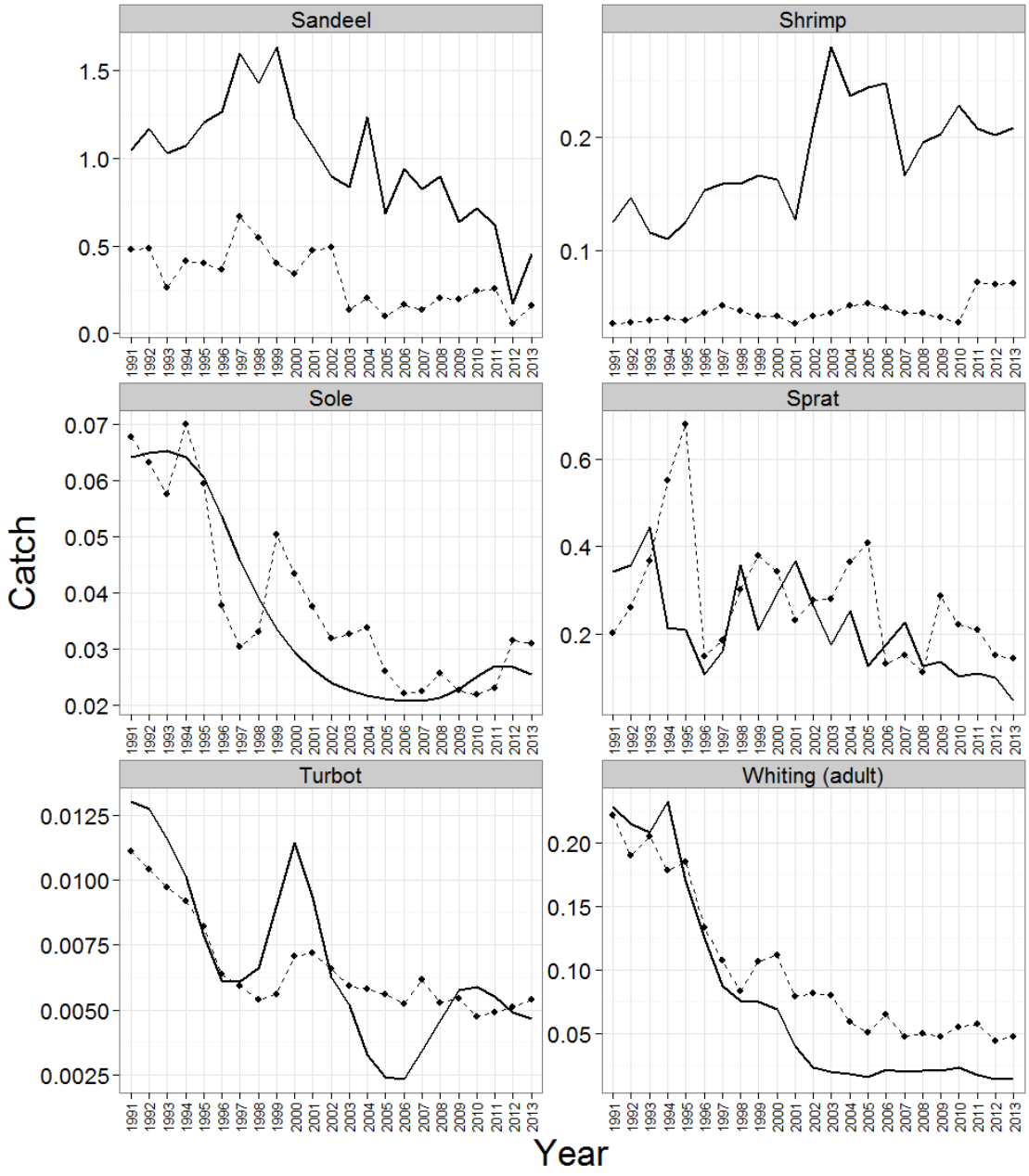
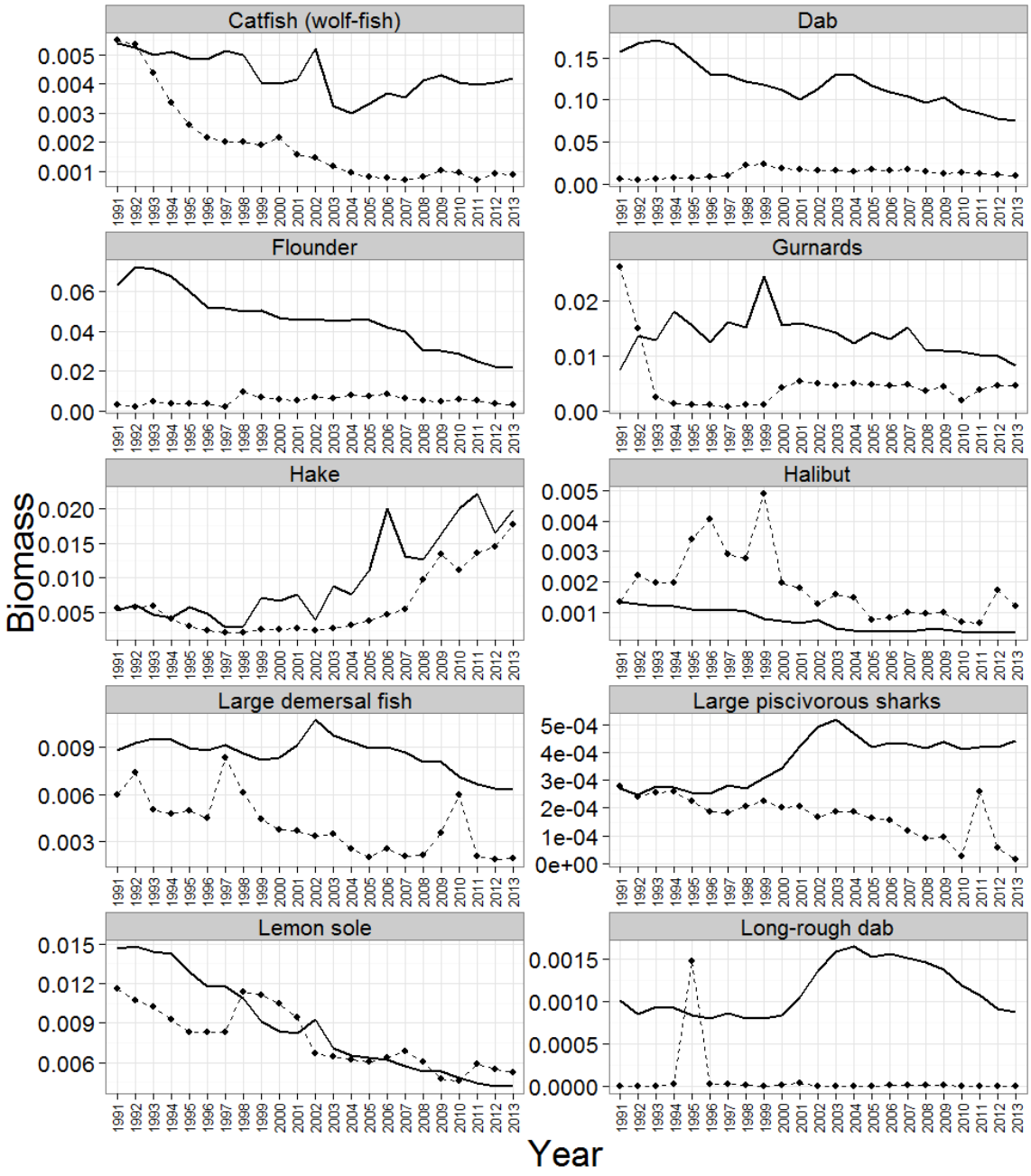
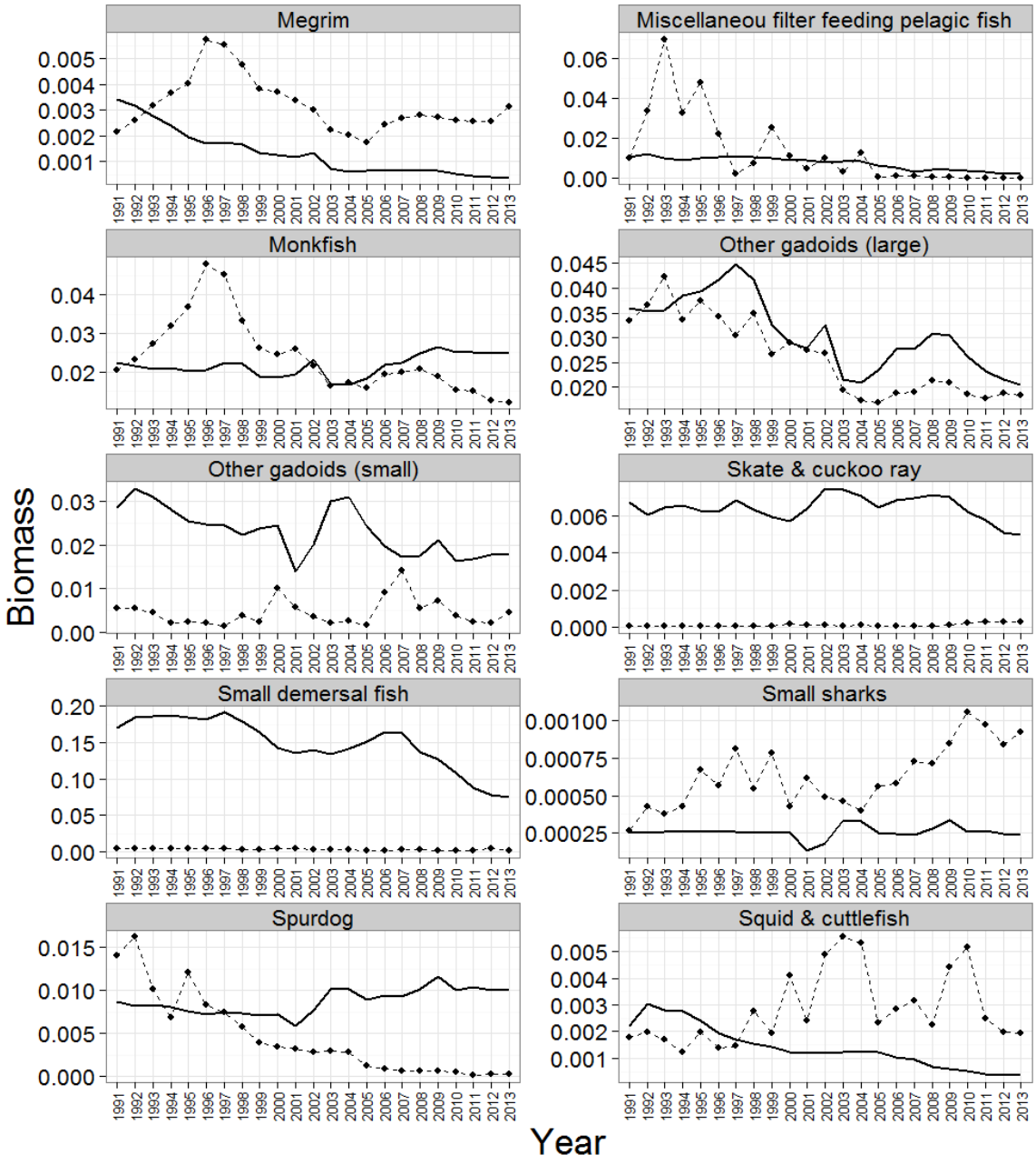


Figure 5.3 Catch plots - observed and model predicted. Assessed species. 'Observed' catch data are derived from single species stock assessments where available, otherwise from ICES catch statistics (for Starry ray & others, Lemon sole & gurnards).


Catfish (wolf-fish)
Dab
Flounder
Gurnards
Hake
Halibut
Large demersal fish
Large piscivorous sharks
Lemon sole
Long-rough dab
Biomass
Year


Megrim
Miscellaneou filter feeding pelagic fish
Monkfish
Other gadoids (large)
Other gadoids (small)
Skate & cuckoo ray
Small demersal fish
Small sharks
Spurdog
Squid & cuttlefish
Biomass
Year

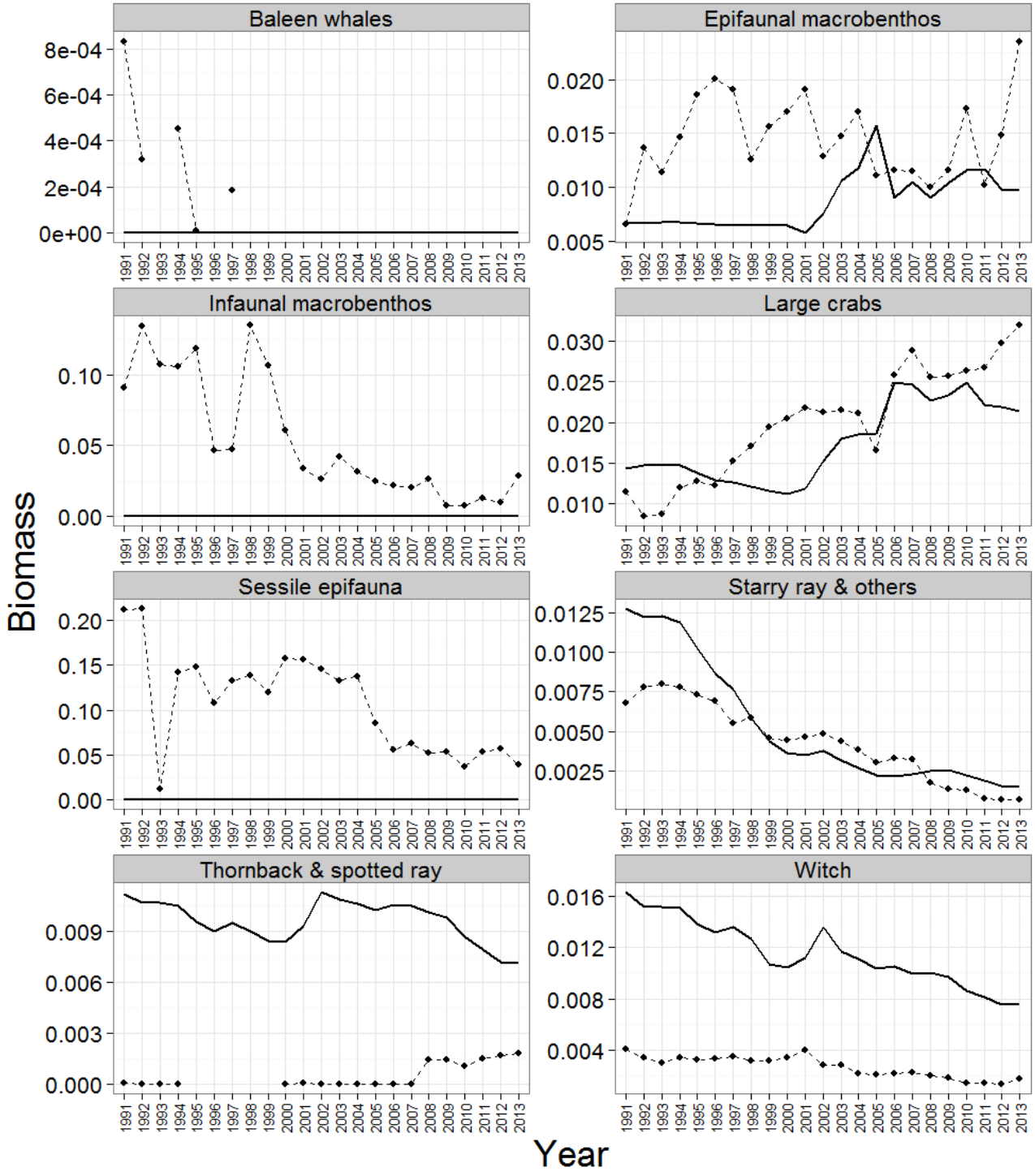


Figure 5.4 Catch plots - observed and model predicted. Non-Assessed species. 'Observed' catch data are derived from single species stock assessments where available, otherwise from ICES landing statistics (for Starry ray & others, Lemon sole & gurnards).

5.1.3. Total mortality

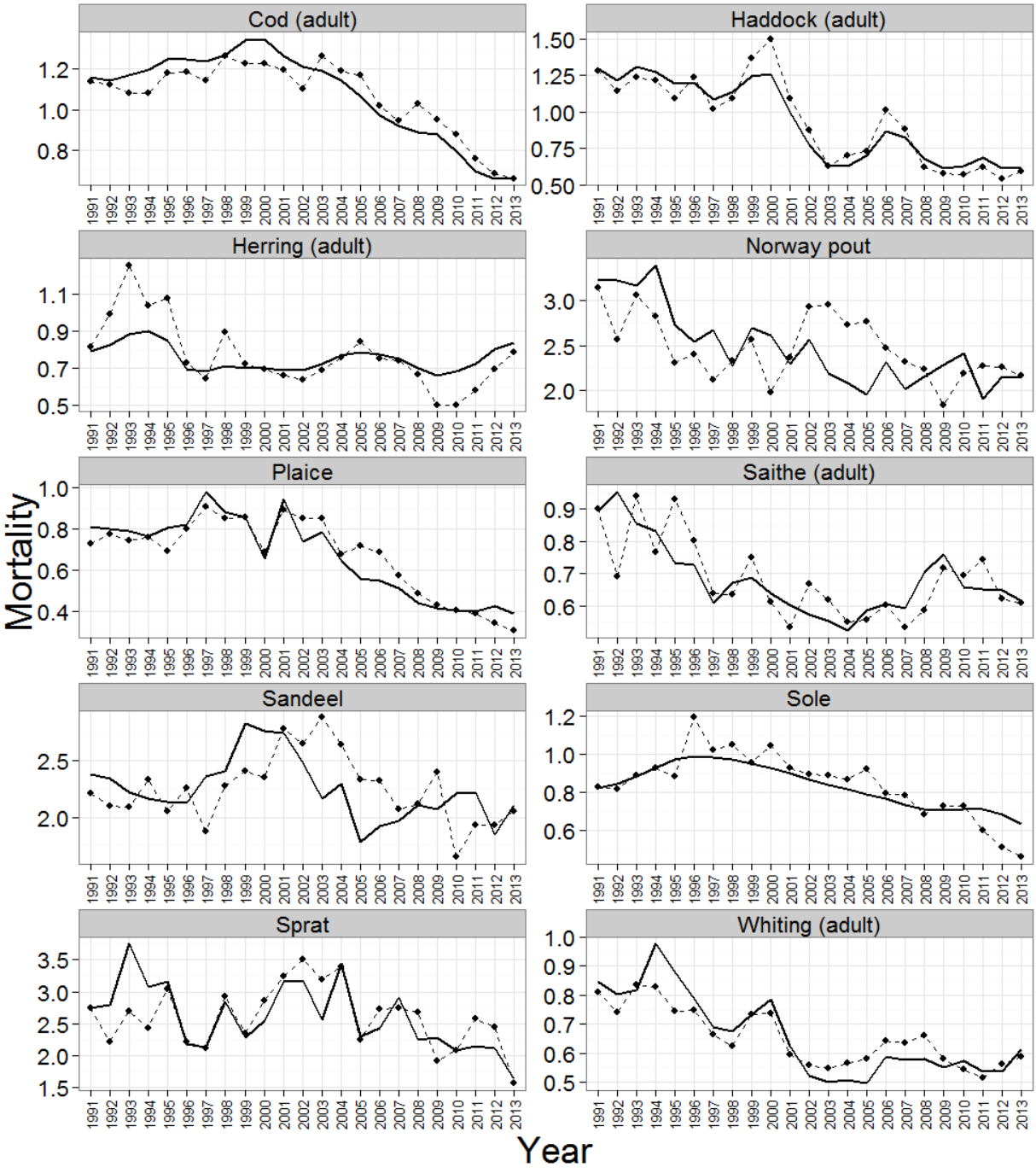


Figure 5.5 Total Mortality (Z) comparison with SMS.Note that Z from SMS is not fitted to in the calibration so serves and a comparison of model predictions.

5.2. Equilibrium estimates of Fmsy and ranges giving 'pretty good yield' close to MSY

Equilibrium simulations were used to estimate Fmsy ranges for each species, taking into account the indirect changes in biomass of other species caused through trophic linkages with the fished species. This 'non-stationary' assessment of Fmsy is performed in Ecosm by running a long simulation (100+ years) in which *F* of the harvested species is incremented or decremented slowly, while holding all other *F*s constant at the Ecopath base values and taking the *F* that results in the maximum average catch (i.e., MSY). The equilibrium simulations set the partial derivatives of the differential equations that define Ecosim with regard to fishing mortality equal to zero to identify the biomass values of each species that would result from the continued application (100+ years) of the different levels of fishing mortality on a particular species. This analysis is called a 'full compensation assessment' sensu Walters *et al.* (2005).

The equilibrium analysis can also be performed by varying the relative effort of each fleet while holding the effort of the other fleets constant, changes in species abundance occurring as a result of changes in effort and indirect trophic effects.

In each case we calculated the lower and upper values of F or effort corresponding to 80% and 95% of MSY.

5.2.1. Species Table FMSY ranges

Table 5.1. NS-EwE estimated Fmsy ranges compared with two multispecies models, SMS and LeMans, and ICES estimates based on single species models for the North Sea.

FG #	Group/ Species	EwE-NS Key Run 2016 (80% MSY)	Lemans 90% lower and upper CL round ensemble mean Fmsy (Thorpe *et al.* 2015)	SMS Fmsy range (but median SSB may be <Bpa)	ICES WKREF3 single species LowFmsy	ICES WKREF3 single species HighFmsy
6	Spurdog	0.13–0.33				
7	Large piscivorous sharks	0.11–0.4				
8	Small sharks	0.13–0.39				
10	Starry ray + others	0.12–0.16				
11	Thornback & Spotted ray	0.22–0.66	0.14–0.26			
12	Skate + cuckoo ray	0.09–0.32	0.09–0.13			
13	Cod (juvenile 0–2)	0.68–1.28				
14	Cod (adult)	0.38–0.96	0.17–0.27	0.3–0.6	0.13	0.33
15	Whiting (juvenile 0–1)	0.85–1.22				
16	Whiting (adult)	0.41–0.85	0.46–1.03	0.05–0.15	0.144	0.15

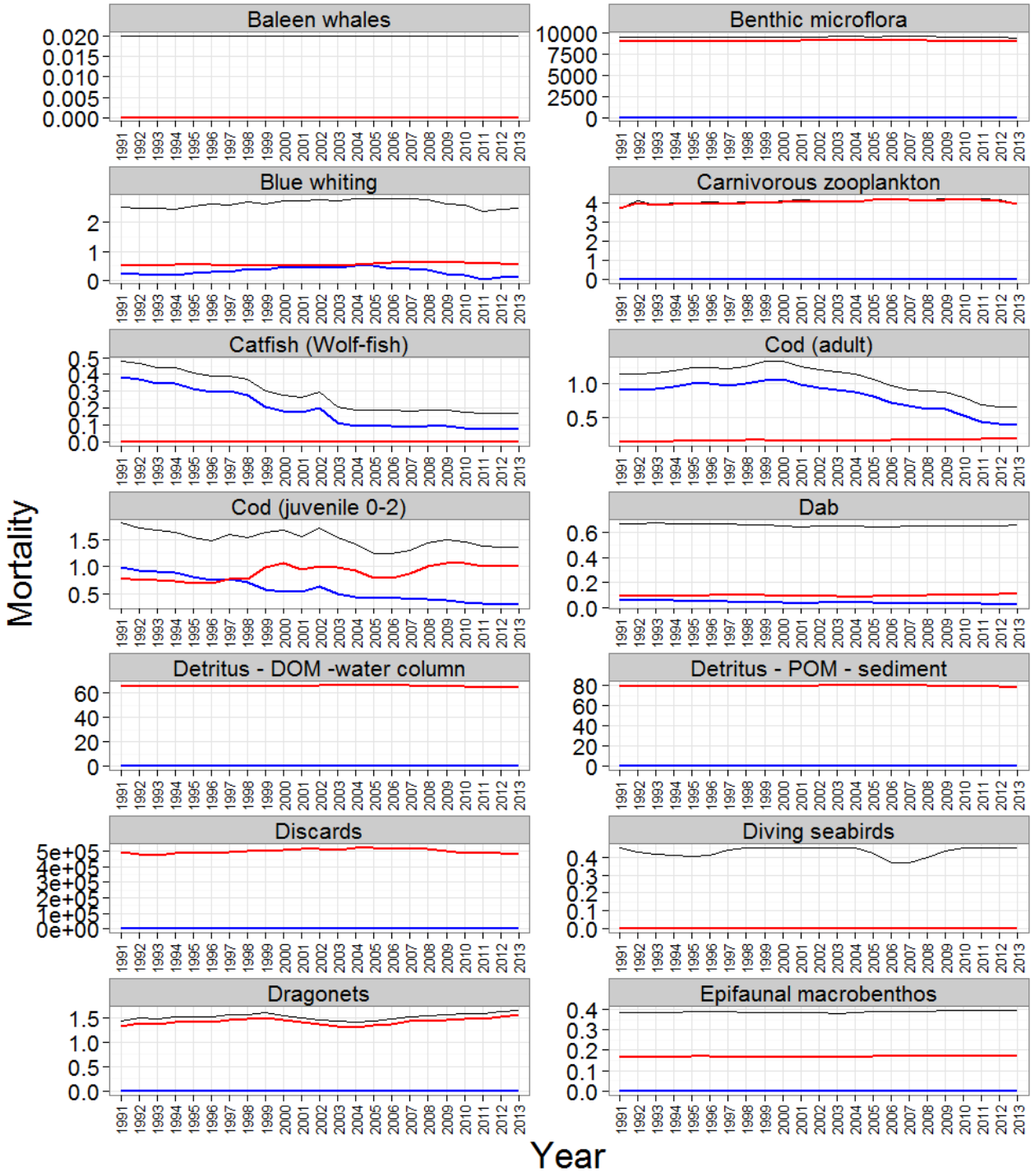
FG #	Group/ Species	EwE-NS Key Run 2016 (80% MSY)	Lemans 90% lower and upper CL round ensemble mean Fmsy (Thorpe *et al.* 2015)	SMS Fmsy range (but median SSB may be <Bpa)	ICES WKREF3 single species LowFmsy	ICES WKREF3 single species HighFmsy
17	Haddock (juvenile 0–1)	0.59–1.28				
18	Haddock (adult)	0.31–0.67	0.3–0.72	0.3–0.6	0.25	0.51
19	Saithe (juvenile 0–3)	0.54–1.03				
20	Saithe (adult)	0.3–0.73	0.21–0.45	0.4	0.2	0.42
21	Hake	0.21–0.49			0.24	0.24
22	Blue whiting	0.39–1.08				
23	Norway pout	0.53–1.26	0.52–1.16	0.3–0.6	0.35	0.35
24	Other gadoids (large)	0.4–1.06				
25	Other gadoids (small)	0.45–0.64	0.5–1.08			
26	Monkfish	0.21–0.62	0.15–0.25			
27	Gurnards	0.15–0.22	0.54–1.19			
28	Herring (juvenile 0–1)	0.33–0.72				
29	Herring (adult)	0.22–0.37	0.35–0.73	0.25–0.4	0.24	0.38
30	Sprat	0.3–0.77	0.52–1.04	0.4–0.7	0.32	0.4
31	Mackerel	0.11–0.34	0.32–0.67		0.22	0.22
32	Horse mackerel	0.15–0.39	0.35–0.8		0.044	0.06
33	Sandeels	0.39–1.02	0.67–1.57	0.3–0.6	0.2	0.3
34	Plaice	0.16–0.46	0.15–0.5		0.13	0.27
35	Dab	0.17–0.28	0.57–1.15			
36	Long-rough dab	0.01–0.01	0.54–1.14			
37	Flounder	0.41–1.25				
38	Sole	0.18–0.39	0.44–0.99		0.24	0.41
39	Lemon sole	0.2–0.52	0.33–0.69			
40	Witch	0.23–0.68	0.24–0.49			
41	Turbot	0.16–0.48				
42	Megrim	0.18–0.51			0.26	0.33
43	Halibut	0.04–0.13				
45	Catfish (Wolf-fish)	0.09–0.39				
46	Large demersal fish	0.14–0.45				
47	Small demersal fish	0.43–0.81				
48	Miscellaneous filter feeding pelagic fish	0.73–1.7				
49	Squid & cuttlefish	0.14–0.18				
54	Large crabs	0.05–0.06				
55	Nephrops	0.02–0.05			0.09	0.12
58	Shrimp	1.97–4.27				

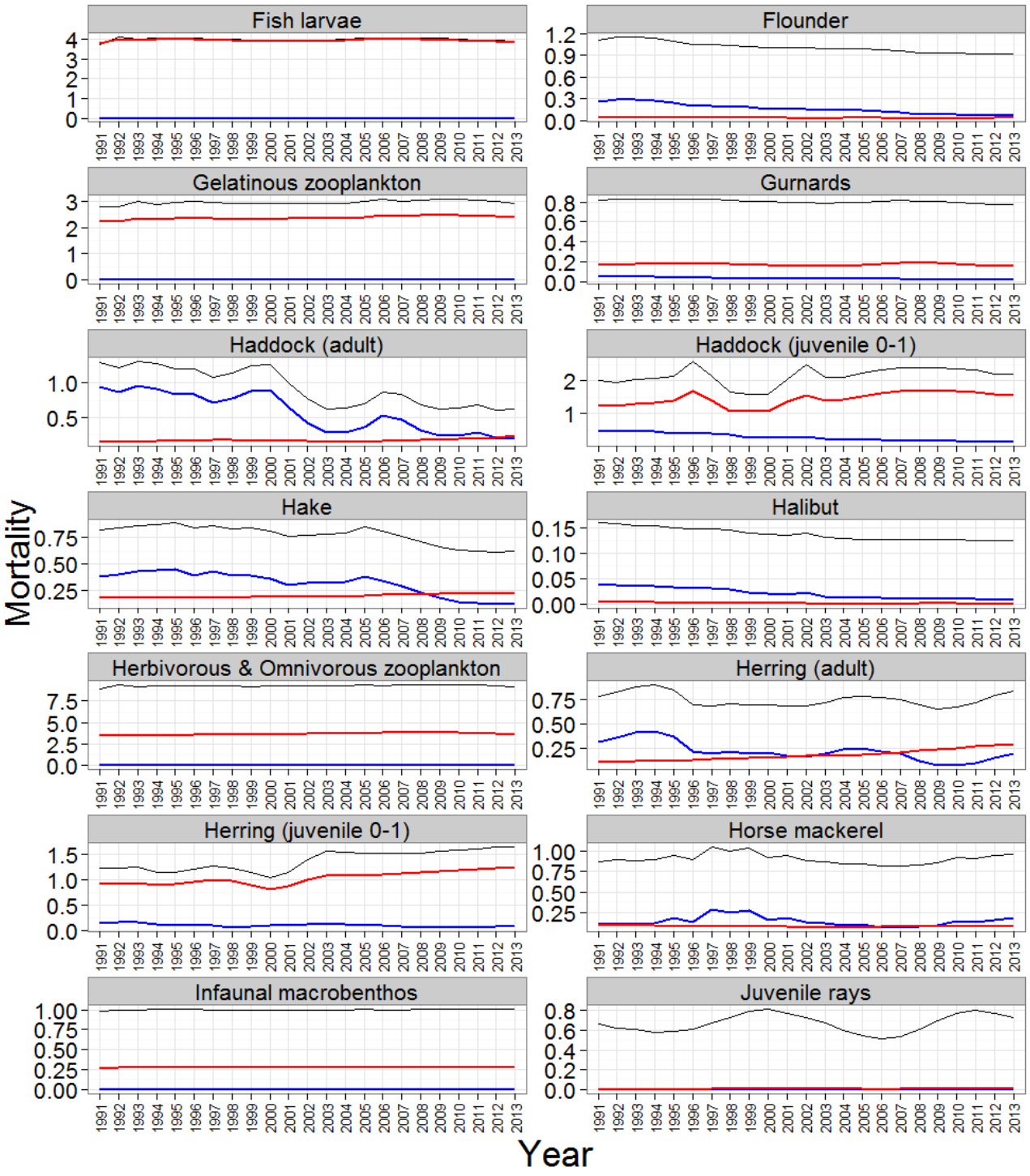
5.2.2. Fleet relative effort at MSY – Value

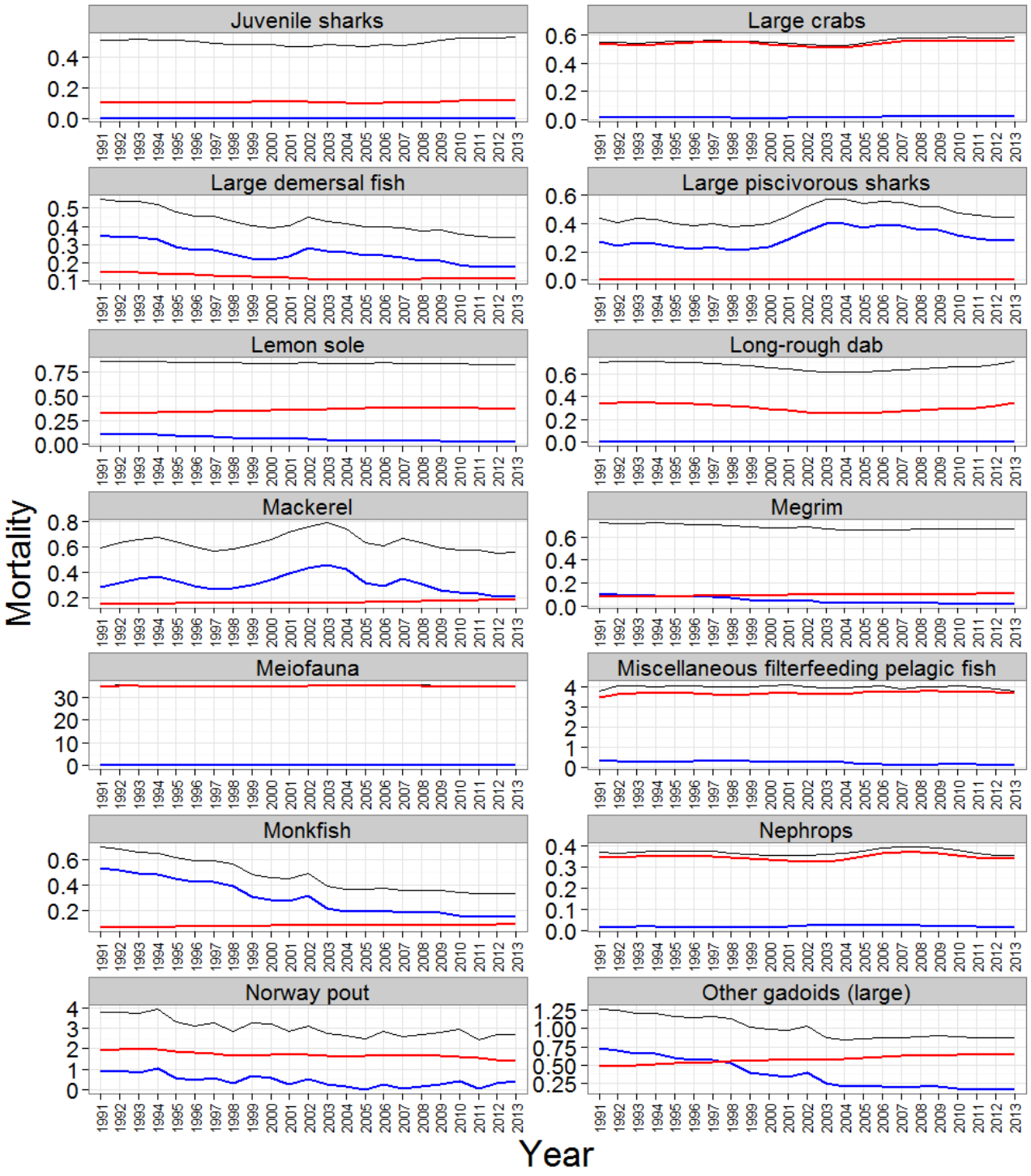
Table 5.1. Fleet relative effort at MSY. The amount of effort relative to that in 1991, which provides the Maximum Sustainable Yield for each modelled fleet.

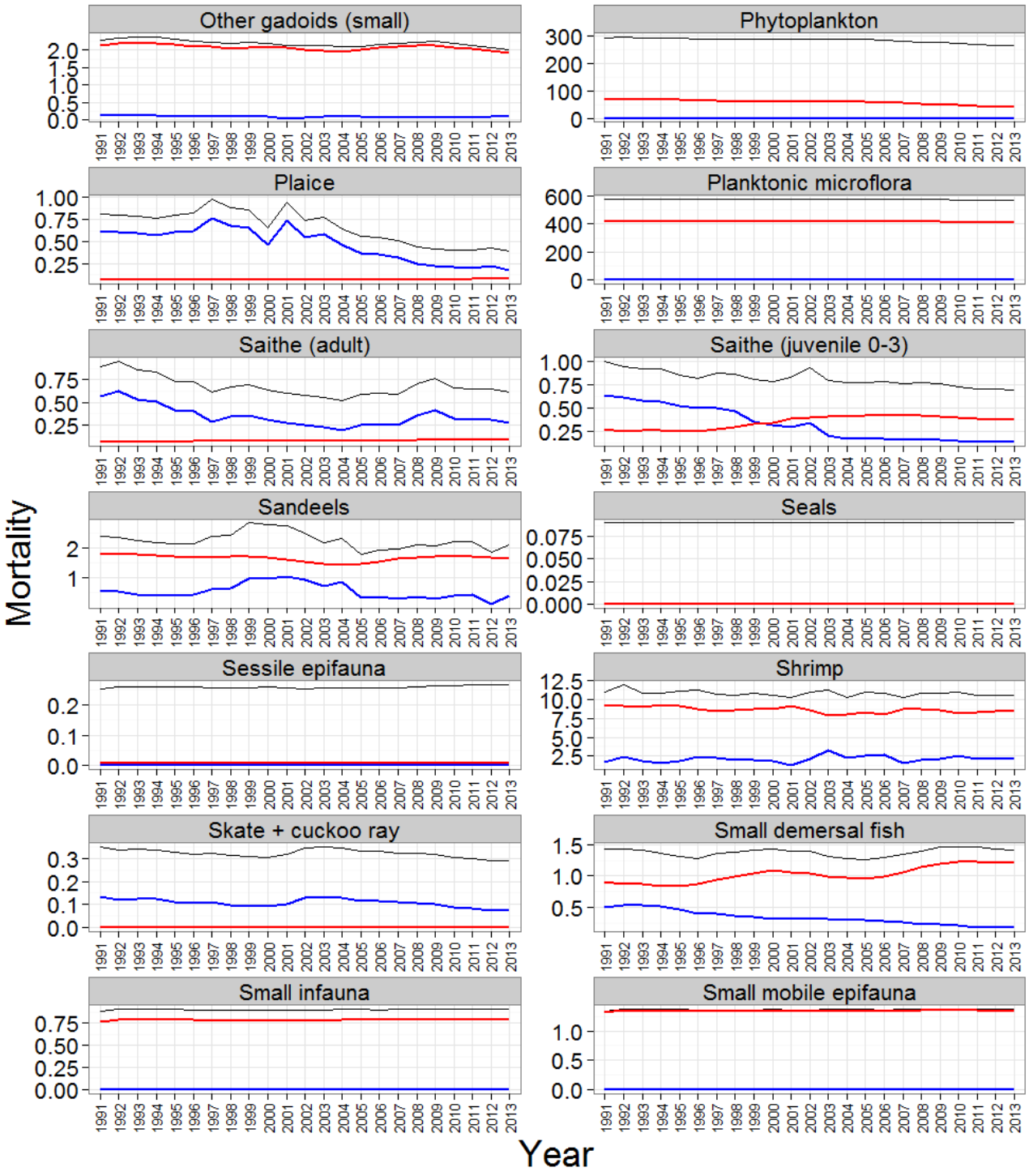
Model FLEET	Relative 1991 Effort at 80% MSY	Relative 1991 Effort at 95% MSY
Beam trawl	0.09 - 1	0.39 - 0.7
Demersal trawl + dem seine	1.45 - 4.94	3.27 - 4.94
Dredges	0.09 - 4.94	0.09 - 4.94
Drift and fixed nets	0.09 - 3.73	0.09 - 1.3
Gears using hooks	0.09 - 4.94	0.09 - 4.94
Industrial trawl	1.76 - 4.94	3.88 - 4.94
Nephrops trawl	0.85 - 4.94	4.03 - 4.94
Other	0.85 - 4.94	3.12 - 4.94
Pelagic trawl	0.09 - 4.94	0.09 - 0.24
Pots	0.09 - 4.94	0.55 - 4.94
Shrimp trawlers	0.09 - 4.94	0.09 - 3.88

5.3. Morality rates time-series - Predation and Fishery (partial F's)




Fish larvae
Flounder
Gelatinous zooplankton
Gurnards
Haddock (adult)
Haddock (juvenile 0-1)
Hake
Halibut
Herbivorous & Omnivorous zooplankton
Herring (adult)
Herring (juvenile 0-1)
Horse mackerel
Infaunal macrobenthos
Juvenile rays
Mortality
Year


Juvenile sharks
Large crabs
Large demersal fish
Large piscivorous sharks
Lemon sole
Long-rough dab
Mackerel
Megrim
Meiofauna
Miscellaneous filterfeeding pelagic fish
Monkfish
Nephrops
Norway pout
Other gadoids (large)
Mortality
Year


Other gadoids (small)
Phytoplankton
Plaice
Planktonic microflora
Saithe (adult)
Saithe (juvenile 0-3)
Sandeels
Seals
Sessile epifauna
Shrimp
Skate + cuckoo ray
Small demersal fish
Small infauna
Small mobile epifauna
Mortality
Year

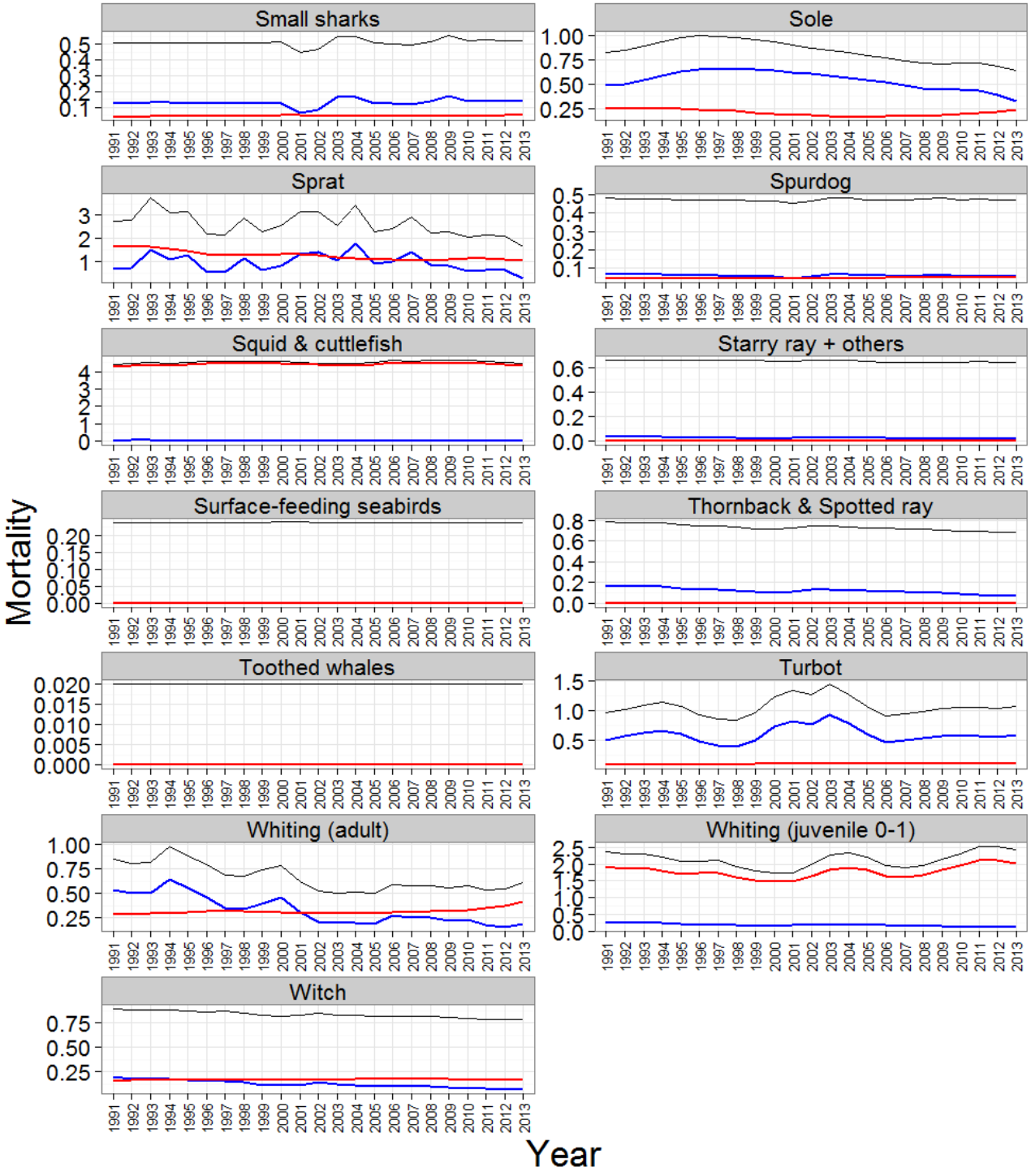


Figure 5.7. Changes in fishing (blue), predation (red) and total mortality (black).

5.4. Ecosystem indicator trends

All output files of ecosystem metrics describing the state of the North Sea ecosystem in 1991, and changes from 1991–2013 in system and community level indicators are given in 2 data files

1. **NSea 1991_Key Run_Ecosystem Indices_Ecopath.xls** - which includes the outputs metrics from the balanced Ecopath model and thus serve as 'state' descriptors

2. **NSea 1991_Key Run_Time-series Indicators.xlsx** - which includes plots of the indicators derived from the calibrated Ecosim key run.

Changes in selected system and community indicators are shown in Figure 5.8. Referring to the figure panels, these include:

(a) Primary production and model predicted PP anomaly
(b) Model predicted primary production (note: this is predicted to increase due to declining zooplankton predation, which is in turn a consequence mainly of increasing predation by herring)
(c) Trends in total system biomass and biomass of demersal fish, pelagic fish and benthos
(d) Community indices – Demersal/ Pelagic fish and Fish/Benthos
(e) Fish, biomass and catch
(f) Total catch/biomass – as a measure of the overall fishing pressure
(g) Trophic level of the catch – catch weighted by trophic level – representing the mean TL of the catch, often referred to as the Marine Trophic Index. TL of catch captures how removal of top predatory fish results in catches dominated by small, lower TL species. It is expected to decrease with fishing (Pauly *et al.*, 1998, Shannon *et al.*, 2009). It has been the subject of controversy.
(h) Trophic level of the biomass – TL weighted by biomass – representing the mean TL of the system. Two indices are given, one that includes only assessed fish, the other including all groups.
(i) Fish community biomass trends – small (<40cm) and large fish (>40cm)

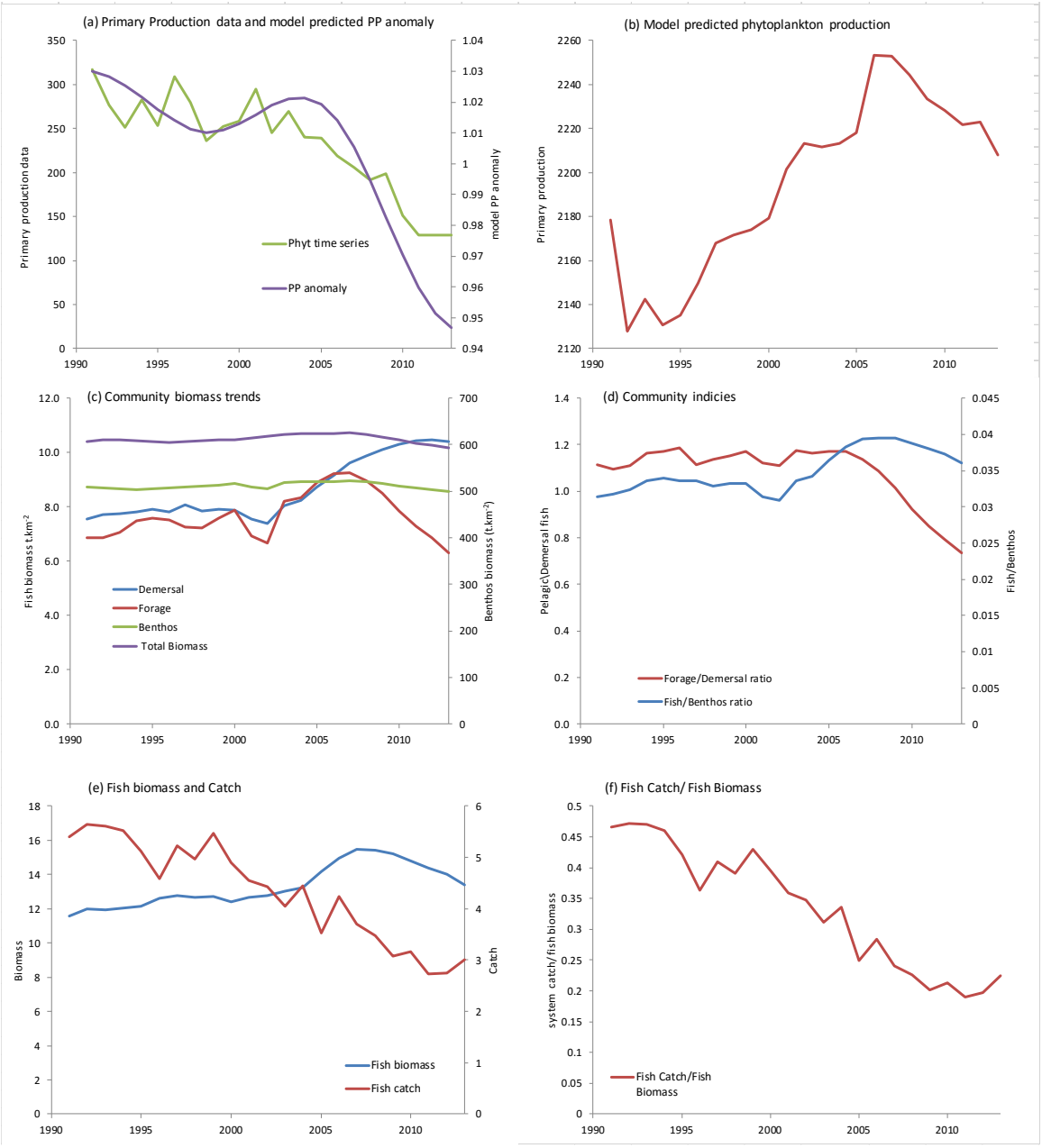

(a) Primary Production data and model predicted PP anomaly
Primary production data
model PP anomaly
Phyt time series
PP anomaly
(b) Model predicted phytoplankton production
Primary production
(c) Community biomass trends
Fish biomass t.km-2
Benthos biomass (t.km-2)
Demersal
Forage
Benthos
Total Biomass
(d) Community indicies
Pelagic\Demersal fish
Fish/Benthos
Forage/Demersal ratio
Fish/Benthos ratio
(e) Fish biomass and Catch
Biomass
Catch
Fish biomass
Fish catch
(f) Fish Catch/ Fish Biomass
system catch/fish biomass
Fish Catch/Fish Biomass

Figure 5.8. Ecosystem indicators derived from the model key run.

6. File Inventory

	Location	Name	Description
The Key run model	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model	Keyrun 2015_NorthSea1991_12Jan16.eweaccdb	The model
Ecosim scenario		Basic setup	
Time-series file	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model	North Sea Time Serie 1991_2013_12Jan2016.csv	Time-series file for forcing and fitting data (can also be loaded driectly from the database)
Output files (from Results Extractor)	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Ecosim FunctGroup and Fisheries.xlsx	For each FG - yearly values of biomass, catch, predation mortality, fishing mortality, and integrated biomass over the period. NOTE: Functional groups listed alphabetically. Landings, discards and total catch per fleet for each prey, plus effort by year for each fleet
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Ecopath Indicators.xlsx	Outputs for Ecopath initial parameters in the file used, including: Basic estimates, fisheries catch quantities and value, search rates, electivity, predator and prey overlap matrices, respiration, consumption, fishing mortalities, predation mortality and mortality coefficients,

			key indicies
Output files (Eco-sim)	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Biomass_annual.csv	Yearly biomass for each FG
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Cons_biom_annual.csv	Yearly Q/B values for each FG
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	FeedingTime_annual.csv	Yearly feeding time factor for each FG
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Mortality_annual.csv	Yearly Total Mortality (Z) for each FG
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Prey_annual GROUP NAME.csv	Yearly predation mortality on the selected (viewed group) by its predators
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Predation_annual GROUP NAME.csv	Yearly proportion of each prey in the diet of the selected predator

	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	TL_annual.csv	Yearly TL for each FG
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Weight_annual.csv	Yearly average weight for each FG
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	TotalCatch_annual.csv	Total yearly catch
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	FIB_annual.csv	Fishing in balance index yearly
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	KemptonsQ_annual.csv	Kemptons Q Biomass diversity index yearly
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	TLC_annual.csv	Trophic level of the catch, yearly
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Value_annual.csv	Value of fisheries

	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs	Yield_annual.csv	Yearly catch for each FG
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs\Fitting results	Biomass Scaled Predicted and Observed.csv	For each relative biomass time-series (type 0), yearly values for the time-series data side-by-side with the model predictions for biomass. Predicted biomass scaled to observed by y=qB (see spreadsheet Scaled Corrected fitting Plots_NorthSea 2015 Key Run.xlsx)
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs\Fitting results	Catches Predicted and Observed.csv	For each catch time-series (type 6), yearly values for the time-series data side-by-side with the model predictions for catch
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs\Fitting results	Mortality Z Predicted and Observed.csv	For each total mortality (z) time-series (type 5), yearly values for the time-series data side-by-side with the model predictions for biomass
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs\Fitting results	Fitting Diagnostics.xlsx	Sums of squares and yearly residuals for each function group
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs\MSY	Fmsy Ranges.xlsx	Fmsy ranges for 80% of MSY and 95% MSY ('Pretty Good Yield'). The file contains F values for species and also the Relative effort (multipliers) relating to each fleet fishing fishing at 80% and 95% of MSY across the species they catch.

	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs\MSY	Mortality _F_M_Z.xlsx	Yearly predictions of fishing mortality, predation mortality and total mortality
		EwE6-NA_monthly_IndicesWithoutPPR.csv	Monthy values of key network indicators (except PPR)
		EwE6-NA_annual_IndicesWithoutPPR.csv	Yearly values of key network indicators (except PPR)
Excel support files			

	Location	**Name**	**Description**
Key Run Ecopath supporting files			
		Mortality difference ecopath - ecosim_Balancing iter.xlsx	File used in assist in making choices during the ecopath model balancing, particularly regarding the need to get the biomass and the F consistent with assessment data. Used to see if the interannual variability in biomass of F might be outside the range of adjustment.

	L:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015	NSea 2015 KEY RUN Snapshot	All inputs for Ecopath and Ecosim required to 'rebuild' a database by cutting and pasting from Excel. Plus all the key output diagnostics from Ecopath such as mortalities, consumptions and ecosystem metrics
Report supporting files	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 Report	Annex 1 All available data plots.docx	Plots of all the data gathered for possible use in the model calibration.
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 Report	Annex 2 Ecopath Balancing.docx	Detailed steps of the ecopath model balancing process and decisions made
Data support files	L:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 Report	Ecopath Group Changes_KeyRun2015.xlsx	Table detailing the changes to ecopath parameters since the previous key run. The table is in the report
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\Update of the time-series\Fishing effort\Fishing Effort Reverse Engineer	STECF effort data 2013_Reverse Engineer3.xlsx	Rescaling of the 1991 ecopath model catch proportions such that the catch compostion of each fleet represents recent fleet 'behaviour' necessary for forward simulations, but maintains the F on each species in the 1991 balanced ecopath model

	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\Update of the time-series\Fishing effort\Fishing Effort Reverse Engineer	EWEdiscards.xlsx	Calculation of proportions of discards and landing of juveniles and adults in multistanza groups based on WGNSSK 2014 report. Used in STECF effort data 2013_Reverse Engineer3.xlsx.
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Ecosim outputs\Fitting results	Scaled Corrected fitting Plots_NorthSea 2015 Key Run.xlsx	Spreadsheet for re-scaling the observed values of biomass so that the predicted and observed outputs are on the correct scales. (see Biomass Scaled Predicted and Observed.csv above). OLDER file (useful if using excel ' Fitting Plots_Annual_Scaled Biomass and Others TEMPLATE FOR KEY RUNS.xlsx' for use as a template
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Industrial fleet specification	STECF effort data 2013_Industrial fleet.xlsx	Effort data series, corrected for updating the sandeel trawl to Industrial Trawl
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model\Industrial fleet specification	Industrial Fleet specification_immediate fix.xlsx	Immediate fixes applied to change aggregate sandeel trawls in to industrial trawls fleet
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model	Sums of Squares improvements2_Steve2.xlsx	File used to compare various alternative parameterisations during calibration
	O:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model	2015 KeyRun Calibration and testing file_Local.xlsx	File used during preparation and calibration to time-series data. Includes setup and templates for evaluating residuals, testing plots and group info settings, SR parameters and exploring any

			aspects of the fitting processes.
	L:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model	SRplots_Data.xlsx	Plots of relative slopes of R/SSB and SR series for those commercial species defined as multi-stanza groups in the model
	L:\Foodweb Models\Ecopath\North Sea\1991\Key run 2015\KeyRun 2015 model	SRplot_graph_S-R plot.xlsx	Plots of the stock recruitment relationships emerging from the model when a V shaped fishing pattern is applied to all multistanza groups at the same time and all all forcing functions and other fishing are turned off. Plus when the V pattern is applied to each group alone. Also compares the relative degree in compensation (slope of R/SSB) with single species data from 'SRplots_Data.xlxs'
R Code for data formatting		Various R codes for data formatting and plotting	

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