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E-mail: EASME-EMFF-CONTRACTS@ec.europa.eu

European Commission
B-1049 Brussels

Authors: Jan Jaap Poos, José De Oliveira, Clara Ulrich, Thomas Brunel, Kristian Schreiber Plet-Hansen, Tobias Mildenberger, J. Rasmus Nielsen, Alexandros Kokkalis, Cóilín Minto, Lionel Pawlowski, Marianne Robert, Claire Macher, Mathieu Merzéréaud, Dorleta Garcia, Leire Ibaibarriaga, Michel Bertignac, Youen Vermard, Simon Fischer, Piera Carpi, Nicola Walker, Timothy Earl, Sarah Davie, Holger Haslob, Alexander Kempf, Marc Taylor, Paloma Martin, Francesc Maynou, Laura Recasens, John Gabriel Ramírez, Jordi Lleonart, Mariona Garriga, George Tserpes, Viki Sgardeli, Gianpaolo Coro, Giuseppe Scarcella, Silvia Angelini

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Abstract

This is the final report of the European Commission funded research project "DRuMFISH" (service contract n° EASME/EMFF/2014/l.3.2.4/ SI2.721116). The main aim of the project was to develop models and strategies for providing advice for mixed fisheries that account for: (i) fishing mortality ranges consistent with MSY, (ii) all fish caught being landed, and (iii) significant components of the marine fish ecosystem lacking key biological information. In order to meet this aim, DRuMFISH delivered a review of assessment approaches for data-poor stocks, extended mixed fisheries simulation frameworks to include data-poor stocks. The assessment approaches and simulation frameworks were implemented in 7 case studies. These case studies were mixed fisheries in the Baltic Sea, the North Sea, the Celtic Sea, the Bay of Biscay, the Western Mediterranean, the Adriatic Sea, and the Aegean Sea. Within the case studies, 35 data-poor stock assessments were done. These assessments provided exploitation status of data-poor stocks. Different harvest control rules were subsequently tested for their expected yields and stock biomasses from the mixed fisheries in the simulation frameworks. Now that data-poor stocks can be incorporated with in the mixed fisheries simulation frameworks, the design of new management plans can account for data-poor stocks in mixed fisheries.

1. Executive summary

1.1. Background

Most of the management plans implemented in the EU before the 2013 reform of the Common Fisheries Policy (CFP) are based on single-stock considerations and are not designed to deal with mixed fisheries. Currently, regional management plans (such as the multi-annual plan for the North Sea demersal fisheries) are being developed, where management rules can explicitly account for mixed fisheries in the setting of annual TACs. The exploitation status of data-poor stocks is often unknown, and the evaluations of such management plans have therefore focused mainly on data-rich stocks. If future management plans in the EU are to include data-poor stocks, models and strategies for providing advice need to be extended to explicitly account for mixed fisheries.

The main aim of the DRuMFISH project was to develop models and strategies for providing advice for mixed fisheries that account for: (i) fishing mortality ranges consistent with MSY, (ii) all fish caught being landed, and (iii) significant components of the marine fish ecosystem lacking key biological information.

In order to meet this aim, DRuMFISH: (i) delivered a review of assessment approaches for data-poor stocks, (ii) extended mixed fisheries simulation frameworks to include data-poor stocks, and (ii) implemented these methods in seven case studies. Below, we give an overview of the main achievements in more detail.

1.2. Main achievements

A seminar with experts on the topics of data-poor stock assessments and mixed fisheries was organised in the first year of the project to ensure that the project captured the latest developments in the research areas. The invited experts came from Australia, South-Africa, and the US. Policy experts from the European Commission (Directorate General for Fisheries and Maritime Affairs) were also invited to join and interact with the experts.

The review of data-poor stock assessment approaches covered catch-based approaches (catch-only methods with supplementary information), life-history, per-recruit and length-based approaches, as well as qualitative and semi-quantitative approaches. The review provides the authorship, title, and abstract of each approach, along with a summary of the data requirements, the assumptions underlying the methods, and the outputs. The review is available online[1] and was presented at ICES WKLIFE workshops in 2016 and 2017.

Two of the assessment methods reviewed have been incorporated into the ICES advisory framework: CMSY for data-limited cases and SPiCT for data-moderate cases. The latter was partly developed in the DRuMFISH project. These two methods were then applied to assess a selection of data-poor stocks across case studies, leading to 10 and 20 new stock assessments with CMSY and SPiCT, respectively. These methods were chosen because their data requirements corresponded to the data availability in the different case studies (i.e. CMSY for stocks with catch data only and CMSY or SPiCT for stocks with catch data and one or several abundance indices). The choice of SPiCT for the four case studies outside of the Mediterranean was also motivated by the increasing use of this model at ICES. In this context, the DRUMFISH project contributed directly to the work of ICES, and in return could benefit from the peer-review procedures conducted in ICES working groups. These peer-reviews concluded that the quality of most assessments was satisfactory to be used in the ICES advisory process. At least five assessments have subsequently been used in the ICES WGNSSK, the expert working group that evaluates the exploitation status of North Sea stocks.

Beyond CMSY and SPICT, several other assessment methodologies were implemented, leading to a total of 35 new data-poor stock assessments (Table 1). These do not, however, cover every single data-poor stock within each case study, and the highest priority was given to the data-poor stocks

[1] www.drumfish.org/WP2

Table 1. Overview of data-poor and data-moderate stocks that have been assessed within the different DRuMFISH case studies. F is the fishing mortality and F_{MSY} is the estimated fishing mortality at which maximum sustainable yield is achieved. B is the stock biomass and B_{MSY} is the expected biomass obtained when fishing mortality is at F_{MSY}. Question marks indicate that fishing mortality or biomass in relation to relevant reference points is unknown.

Case study	Data-limited stock assessment	Current stock status: F	Current stock status: Biomass	Assessment quality
Baltic Sea	Flounder (SPiCT[2])	$F<F_{MSY}$	$B> B_{MSY}$	Exploratory only
North Sea	Turbot (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Accepted by ICES
	Brill (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Accepted by ICES
	Dab (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Accepted by ICES
	Flounder (SPiCT)	F= ?	B= ?	Poor model fit
	Flounder (length based indicator)	$F<F_{MSY}$		
	Lemon sole (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Accepted by ICES
	Witch (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Accepted by ICES
	Anglerfish (SPiCT)	$F>F_{MSY}$	$0.5\ B_{MSY}<B< B_{MSY}$	Exploratory only
	Thornback ray (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Exploratory only
	Cuckoo ray (SPiCT)	$F<F_{MSY}$	$0.5\ B_{MSY}<B< B_{MSY}$	Exploratory only
Celtic Sea	Cuckoo ray (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Assessment uncertain
	Nephrops (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Poor model fit
	Black anglerfish (SPiCT)	F= ?	B= ?	Poor model fit
	White anglerfish (SPiCT)	$F<F_{MSY}$	$B>= 0.5\ B_{MSY}$	Good model fit
Bay of Biscay	White anglerfish (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	Poor model fit
	White anglerfish (A4A[3])	$F>F_{MSY}$	$B> B_{MSY}$	Good model fit
	Red mullet (SPiCT)	$F>F_{MSY}$	$B< 0.5\ B_{MSY}$	Exploratory only
Western Mediterranean	Hake (CMSY[4])	$F>F_{MSY}$	$B< 0.5\ B_{MSY}$	Models sensitive to assumption on depletion rates
	Red mullet (CMSY)	$F>F_{MSY}$	$0.5\ B_{MSY}<B< B_{MSY}$	
	Hake (VIT[5])	$F>F_{MSY}$	$B< 0.5\ B_{MSY}$	Good agreement with XSA for years in common
	Hake (LB-SPR[6])	F= ?	B= ?	
	Hake (MAGD[7])	F= ?	B= ?	
Adriatic Sea	Great Mediterranean scallop (CMSY)	$F>F_{MSY}$	$B< 0.5\ B_{MSY}$	Models sensitive to assumption on depletion rates
	Sole (CMSY)	$F>F_{MSY}$	$0.5\ B_{MSY}<B< B_{MSY}$	
	Cuttlefish (CMSY)	$F>F_{MSY}$	$0.5\ B_{MSY}<B< B_{MSY}$	
	Queen scallop (CMSY)	$F>F_{MSY}$	$B< 0.5\ B_{MSY}$	
	Brill (CMSY)	$F>F_{MSY}$	$B< 0.5\ B_{MSY}$	
	Murex (CMSY)	$F<F_{MSY}$	$B> B_{MSY}$	
	Mantis shrimp (CMSY)	$F<F_{MSY}$	$B> B_{MSY}$	
	Caramote prawn (CMSY)	$F<F_{MSY}$	$B> B_{MSY}$	
Aegean Sea	Hake (SPiCT)	$F>F_{MSY}$	$0.5\ B_{MSY}<B< B_{MSY}$	Decent model fits for most stocks that improved when using priors for population growth rate, and interpolation of years with missing abundance indices
	Red Mullet (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	
	Striped red mullet (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	
	Pink shrimp (SPiCT)	$F<F_{MSY}$	$B> B_{MSY}$	

[2] stochastic surplus production model in continuous time
[3] "assessment for all" stock assessment model
[4] catch MSY model
[5] pseudo-cohort VPA model
[6] length-based spawning potential ratio
[7] multi-annual generalised depletion model

selected based on two criteria: (i) the stock was data-poor, but sufficient data were available that could be used for data-poor assessment methods, and (ii) the stock was part of a mixed fishery. The development of new assessments for data-limited stocks within DRuMFISH made it possible to include these stocks in mixed fisheries forecasts in the same manner as data-rich stocks. These forecasts were made using mixed fisheries simulation frameworks used by ICES and STECF. Mixed-fisheries harvest control rules based on fishing mortality ranges compatible with MSY can thus be evaluated while including data-poor stocks. The impact of the landing obligation, when all fish caught are landed, can also be tested.

Mixed fisheries models can be used to provide either short-term advice for mixed fisheries, or be used to evaluate medium- to long-term management strategies. Short-term mixed fisheries forecasts that included data-poor stocks were carried out for the Baltic Sea, North Sea, and Celtic Sea using Fcube. It carries out a short-term forecast (over the current year and the year for which a TAC advice is given) to estimate the catches that are expected to result from a set of single-stock TACs when mixed fisheries interactions are taken into account. DRuMFISH extended the existing Fcube forecasts for the North Sea and the Celtic Sea with the inclusion of data-poor stocks. The project also developed a first implementation of Fcube with both data-rich and data-poor stocks for the Baltic Sea. For these three eco-regions, results showed that none of the data-poor stocks included in the Fcube forecasts were limiting the effort of the fleets, and are therefore unlikely to be choke species in the short term.

Medium- and long-term mixed fisheries forecasts were carried out for the North Sea, the Bay of Biscay and the Mediterranean case studies. The tools for these forecasts included FLBEIA, Fcube, IAM, and MEFISTO (Mediterranean Fisheries Simulation Tool). The methodological developments made in these tools during DRuMFISH allowed for explicit modelling of the dynamics of the data-limited stocks. The projections of stock biomass, fishing mortalities, and catches for these stocks were presented in different management scenarios.

For the Mediterranean case studies, the management of fisheries through fishing effort control and technical measures (i.e. no TAC system implemented) and the lack of detailed catch and effort information by métier[8] hampered the use of Fcube and FLBEIA. Hence, simpler methods were chosen for the three Mediterranean case studies. The MEFISTO tool was used in the Western Mediterranean Sea case study. The Aegean Sea and Adriatic Sea case studies adopted methods that link fishing mortality to fishing effort, similar to Fcube and FLBEIA. However, the number of fleet components used was small in comparison to the other case studies (two for the Aegean Sea and one for the Adriatic Sea). In general, the outcomes of the Mediterranean case studies suggested that substantial effort reductions were needed to ensure sustainable harvesting of the data-poor stocks in the area.

Limitations

The review of stock assessment methods focused on those methods that use catch and/or catch-per-unit effort measures to estimate the status of data-poor stocks. However, there is a rapidly developing field of assessment methods that are based on the kinship of individuals in the catches. These methods are collectively called Close-Kin Mark-Recapture (CKMR), and the kinship in the catches are determined by means of DNA analysis from a large number of individuals. The CKMR method has been successfully applied to populations of tuna and great white sharks, but was not covered in the assessment review.

The simulation work within DRuMFISH focused on the “technical interactions” aspect of data-poor stocks in mixed fisheries, where stocks are caught together in a single métier. Species interactions within mixed fisheries, such as those caused by predator-prey relationships among species, were not considered. The main reason for not including species interactions is that the simulation tools in DRuMFISH were designed for analysing technical interactions and not inter-specific interactions. The lack of inter-specific interactions in the developed simulation tools potentially affects the precision and accuracy of especially medium- to long-term mixed-fisheries forecasts. However, accounting for

[8] A fishing métier is defined as the use of a given fishing gear in a given area, in order to target a single species or group of species.

technical interactions alone should be adequate for short-term forecasts because changes in the population abundance of predators and prey are expected to be limited in the short-term.

The large geographic spread of the case studies meant that each case study dealt with a very different governance environment. For instance, the data availability for each case study varied. This resulted in the adoption of different strategies for mixed fisheries modelling throughout the project.

All mixed fisheries simulation tools developed and used in the project omit: (i) explicit spatial structure and (ii) complex behaviour that individual vessel operators may exhibit in light of management regulations, although both omissions may be implicitly captured to some extent through catchability differences among fleets and métiers. The reason for these omissions is that including spatial structure or complex behaviour is not yet feasible for operating models such as those used in the project. As a result, some details of management strategies could not be incorporated and quantified. For example, a management system where multiple data-poor stocks share a single quota probably leads to changes in fishing behaviour, but this cannot be modelled explicitly at present.

Recommendations

Based on the findings during the study we recommend:

1) An effort by the Commission to ensure benchmarking of data-poor assessments for stocks in the project that have not been approved for management advice. This seems especially relevant for the Mediterranean case studies, where there is scope for a significant increase in the number of assessed stocks through a wider use of data-poor assessment methods.
2) The evaluation of more regional EU multi-annual plans to include data-limited stocks. Such evaluations can make use of the tools for assessment (e.g. SPiCT), and simulation (e.g. Fcube, FLBEIA) developed within DRuMFISH.
3) The harvest control rules explored in DRuMFISH that use optimisation algorithms[9] should be considered when designing new regional EU multi-annual plans. These rules can be used to formulate mixed fisheries advice that reduces the potential imbalance of quota that occurs when giving single species advice. With these rules, ICES can support the implementation of mixed fisheries management plans, allowing advice to be given on target fishing mortality and catch limits per stock, while staying within F_{MSY} ranges.
4) Data collection and dissemination in the Mediterranean should be improved. While detailed catch and effort data was available for different métiers in the other case studies, such highly detailed métier structure was missing in the Mediterranean.
5) For case studies where a substantial number of stocks were overexploited, for instance in the Western Mediterranean and Adriatic Sea, the project results suggest that stock recovery only occurs if fishing effort is substantially (> 50%) reduced. This reduction should ideally be achieved by developing or updating management plans, for which DRuMFISH tools could be used.

Conclusion

The data-poor assessments and simulation tools developed for mixed fisheries management strategy evaluation have shed light on the exploitation status of a large number of data-poor stocks. The case studies explored management strategies that explicitly included the dynamics of data-poor stocks in mixed fisheries. Where relevant, the effects of the implementation of the landing obligation were included in the forecasts. Meanwhile, the full implementation of such management strategies requires dialogue between stakeholders, managers and scientists to articulate mixed fisheries harvest control rules[10] that fulfil different management objectives.

[9] See for instance Ulrich et al. (2017) Achieving maximum sustainable yield in mixed fisheries: a management approach for the North Sea demersal fisheries. ICES Journal of Marine Science, 74: 566–575.
[10] See section 3.2

1.3. Structure of the document

The project was organized in a number of work packages: a review of the available methods for data-poor stock assessments was done within the "review" work package. However, because data-poor assessments are part of a continuously developing field, the work package also contributed to developing a further understanding of these approaches. This was done by drawing on the expertise of scientists from outside Europe within a dedicated workshop, and by developing, testing and applying methods in the different case studies. The results of this work package are summarised in **Chapter 2**. The main findings of work package 2 are available online[11].

The "simulation test" work package focused on the identification of existing tools to conduct mixed-fisheries simulations. This work package developed the methods required to incorporate the data-poor stocks in the simulation framework for each of the case studies. This also drew on the input from the workshop on data-poor assessment and management methods early on in the project. This work-package also tested candidate methods in advance of their application within the case studies. The results of this work package are summarised in **Chapter 3**.

The "implement" work-package coordinated the implementation of management scenario evaluations in the case studies. Firstly, the data-poor assessment methods were tested for different stocks. Then the management scenarios were established. Once the details of management scenarios were established, they were used to inform the development of a mixed fisheries simulation within the case studies. The results of this work package are summarised in **Chapter 4**. Some of the work under the review and simulation testing work packages was done in the implementation of the case studies. Hence there may be some overlap between the various chapters. Finally, the results in the individual case studies are summarised in **Chapter 5**.

In many cases, the background information for the different work packages is given in the **Annexes.** These annexes are clearly referenced in the main text. The annexes include more detailed case study reports. In addition, the study's findings contributed to the development of a scientific publication; a link to this publication can be found in Annex 18.

[11] www.drumfish.org/WP2

2. Review of data-poor stock assessments

The project required an initial review of the available methods for the management of data-poor stocks. The detailed review was the main output from this work-package. The review is available on the project website (see www.drumfish.org/WP2). As this was very much a developing field, the project itself developed further understanding of these approaches both by drawing on the expertise of scientists from outside Europe and by developing, testing and applying methods. In particular, the project contributed to the development of "Robin Hood" like approaches. The Robin Hood approach refers to the practice of borrowing information from data-rich stock assessments, e.g. trends in fishing mortality and values for parameters of selectivity functions, to assess a data-poor stock, which leads to stock assessments for the most data-poor stocks being informed by those for the most data-rich stocks.

The review covered data-limited approaches, alternatively referred to as "data-poor", and distinct from both data-moderate approaches, which typically include indices of biomass/abundance in addition to catch data and life-history information, and data-rich approaches, which include full analytical assessments. Data-limited approaches covered catch-based approaches (catch-only methods with supplementary information), life-history, per-recruit and length-based approaches, and qualitative and semi-quantitative approaches.

In addition to the assessment methods, a number of scientific publications that compared the performance of methods, provided useful additional insights into the methods presented, and these were included in the review. Also, supplementary approaches that were of interest were covered, including mixed fishery, MPA, PSA and other general approaches. One section covered simulation-tested data-limited harvest control rules. Other methods' reviews, similar to this document, and from which some inspiration was drawn (e.g. Geromont and Butterwort 2014) were covered. Within each review the authorship, title and abstract is supplied, and the paper is generally summarised through the topics "data/information requirements", "assumptions", "outputs expected", "method of operation", "testing", "caveats" and in some cases "ability to project forward/forecast" (the latter topic was added much later, so is not universally used when summarising the papers).

In general, the DRuMFISH project was interested in methods that are able to be used for forward projecting/forecasting, in addition to being readily available to use. These requirements whittle down the methods that would be useful to DRuMFISH. In particular, two methods that have already been used within the ICES advisory system and provide the required tools for DRuMFISH are:

- Catch-MSY (CMSY, Martell and Froese 2013) is a Monte-Carlo method that estimates fisheries reference points (MSY, F_{MSY}, B_{MSY}) as well as relative stock size (B/B_{MSY}) and exploitation (F/F_{MSY}) from catch data and broad priors for resilience or productivity (r) and for stock status (B/k) at the beginning and the end of the time series. Part of the CMSY package is an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM). The main advantage of BSM compared to other implementations of surplus production models is the focus on informative priors and the acceptance of short and incomplete (= fragmented) abundance data for data-limited cases.
- SPiCT, the stochastic surplus production model in continuous time (SPiCT, Pedersen and Berg 2016) for data-moderate cases. SPiCT can model stock dynamics as well as the dynamics of the fisheries. This enables error in the catch process to be reflected in the uncertainty of estimated model parameters and management quantities. Benefits of the continuous-time state-space model formulation include the ability to provide estimates of exploitable biomass and fishing mortality at any point in time from data sampled at arbitrary and possibly irregular intervals.

Both methods produce consistent outputs (they are both biomass dynamic models, and the latter can take on a Schaeffer form, which the former is hard-wired to do), and can be straight-forwardly incorporated into the simulation tools currently available for DRuMFISH.

Other methodologies were also useful. One section of the review focused on comparison and simulation testing of data-poor assessment methods. These tests have found that quantitative catch-only methods (DCAC, DB-SRA, CMSY, etc.) are generally highly sensitive to assumptions about depletion, and semi-quantitative catch-only methods are more negatively biased on average than methods that explicitly model population dynamics with the use of additional fishing effort data. Furthermore, only those methods that dynamically account for changes in abundance and/or depletion perform well at low stock sizes. In essence, there is a high value for including additional information regarding stock depletion, historical fishing effort and current abundance when only catch data are available, but this information is often lacking. In the simulation exercise that compared catch-only methods, CMSY was rated the best performer and was more effective in estimating stock status over short time scales. Despite the fact that CMSY used with only catch data can take the form of, and behave like, a Schaeffer model, a general guideline is that if some fishery-independent information is available, one should always use a full biomass dynamic model (e.g. SPiCT, ASPIC, etc.). Furthermore, regarding SPiCT, simulation work found that for over-exploited stocks, SPiCT was able to correctly identify an undesirable state and hence appropriately invoke a precautionary buffer when needed, thus demonstrating good performance of this model.

Finally, the DRuMFISH project also developed applications of the Robin Hood approach for the North Sea case study, and for the *Nephrops* stocks in a number of case studies combined. The Robin-Hood approach has a relatively long history, but has been formally described in Punt *et al.* (2011) The Robin-Hood approach refers to the practice of borrowing information from data-rich stock assessments, e.g. trends in fishing mortality and values for parameters of selectivity functions, to assess a data-poor stock, which leads to stock assessments for the most data-poor stocks being informed by those for the most data-rich stocks. Bentley (2014) argues a similar approach where prior probability distributions are used to transfer knowledge from data-rich to data-poor fisheries. This practice has been widely recognized as effective whenever the lack of data prevents an assessment, and as such relevant for management of data-poor stocks in mixed fisheries.

3. Development of simulation frameworks

This work-package identified simulation models for management strategy evaluation that were applicable for mixed fisheries, and adapted these so that the data-poor stocks could be included. There are several mixed-fisheries modelling frameworks used in DRuMFISH: Fcube, FLBEIA, IAM, and MEFISTO. These were also applied in several case studies. The choice for these simulation models stems partly from their use in STECF: Fcube has been used extensively for mixed fisheries advice and in the context of evaluating mixed fisheries management plans in STECF (STECF2015a; STECF-15-04) Meanwhile FLBEIA was considered a "correct path to provide a bio-economic modelling framework" in a JRC workshop on bio-economic modelling (Jardim *et al.* 2013). Both FLBEIA and IAM were extensively used for evaluations of management plans in South-western (Bay of Biscay and Iberia) and North-western (Celtic sea) waters in 2015 (STECF 2015b; STECF-15-08). MEFISTO was listed as one of the potential bio-economic models for use within STECF in 2017 (STECF 2017b).

There is an increasing number of stock assessments for data-poor stocks, both in the ICES area and in the Mediterranean Sea (e.g. by fitting SPiCT assessments to data-poor stocks). The contribution of DRuMFISH to the different simulation frameworks means that those data-poor stocks can be included when developing management plans for mixed fisheries. This is relevant because these frameworks have are being used for developing management plans within STECF, but also for giving ICES mixed fisheries advice. The inclusion of data-poor stocks allows for a better dialogue between stakeholders, managers, and scientists to articulate mixed fisheries harvest control rules. In anticipation of such dialogue, several mixed fisheries harvest control rules were tested for the different models within the project.

3.1. Mixed fisheries simulation models

Although the different tools have slightly different approaches to modelling mixed fisheries, it is important to notice that there are also many similarities. First of all, biological stocks and fleets are their essential elements, which interact through fishing effort and catch (Garcia *et al.* 2017). For the forecasting of data-rich stocks, all tools make use of the classical age-based approaches that are used in forecasting stock number at age under different fishing mortalities (Beverton and Holt 1954). The level of the fishing mortalities in these forecasts are based on some kind of (single-species) harvest control rule, where the future fishing mortality depends on the state of the stock, and the policy objectives specified in the current management regime. In addition, all simulation frameworks make an implicit translation of given fishing mortalities for one or more stocks to the corresponding fishing effort that is required by one or more fleets (or métiers). This translation depends on a perceived relationship between fishing effort for a fleet or métier, and the fishing mortality generated by this fishing effort. This relationship is characterized by the "catchability", such that

$$F_{s,m,t} = q_{s,m,t} \, E_{m,t},$$

Where $F_{s,m,t}$ is the (partial) fishing mortality for a stock *s* and métier *m* in year *t*, $q_{s,m,t}$ is the catchability for that stock and métier, and $E_{m,t}$ is the effort for a métier. For data-rich stocks, this equation can be extended to include age. Variations in the catchability reflect fish vulnerability to fishing gear, fishing strategy, and fish biology, including behaviour and response of individuals to environmental factors (Arreguin-Sanchez 1996). By using the métier definition for determining catchability, variations in fishing strategies within fleets are accounted for as much a possible by grouping vessels into activity categories, reducing the variation in catchability.

Fcube: Fcube is a tool for carrying out short term forecast in mixed fisheries (Figure 3.1). The Fcube approach (after Fleet and Fishery Forecast), is a model of mixed fisheries that can be used to assess the consistency between management (TAC and/or effort) advice for species caught together, given the availability and accessibility of data. There are two ways in which Fcube can be used to address mixed fisheries: the first is to show the potential mismatches in catch advice for a single year. This is the main use of Fcube currently (see ICES WGMIXFISH advice for data-rich species). The alternative is to use it as part of a stochastic Management Strategy Evaluation (MSE; sensu Butterworth and Punt 1999). MSEs project stocks into the future while including a management feedback loop. Hence, they simulate a management procedure where a given management rule is used to determine allowed harvest, e.g. a TAC for each projected year. This is generally done based on perceptions of stock biomass and exploitation status that are used as a basis for a short-term forecast. The true (realised) fishing mortality can differ from the target (intended) mortality because of stochastic variation in stock-related variables (e.g. the stock–recruitment relationship, growth, and natural mortality), the assumptions in the short-term forecast, and/or errors in observation and implementation. The forward projections are repeated many times, allowing probabilities of achieving specified objectives (e.g. a level of stock biomass or fishing mortality) to be derived. The harvest control rule in the Fcube MSE implementation annually sets TACs based on the goal of achieving mean fishing mortality consistent with maximum sustainable yield (MSY). The basis for any of the fishing mortalities in the future is thus the F_{MSY} estimate provided by ICES. However, the harvest control rule also follows the "ICES advice sliding rule", which requires a reduction in F when SSB falls below a biomass threshold[12].

Forecasts were performed in Fcube using landings and discards in weight, as well as effort disaggregated by fleet and fishery. A simple linear relationship was assumed between effort and fishing mortality, assuming status quo catchability in the projections (see above equations). Forecasts were produced according to scenarios for what limits the effort in each fleet and the forecasted catch of each species compared to the single-species advice for TAC. Results are presented in a unique advice sheet, and those results relevant to each of the species covered are added to the single-species advice sheets.

Fcube is used to evaluate the discrepancy between the TACs set individually for the main stocks and the actual catches which are likely to be realised when mixed fisheries interactions are taken into account. The tool uses catch and effort data on a fleet basis to estimate the effort corresponding to each of the TACs set for each species, caught by each fleet (assuming constant catchability).

The starting points were thus the single-species TACs, and for each stock, the associated target fishing mortality. The latter is the target fishing mortality resulting from the application of a management plan target or the ICES MSY approach rule. The stock target fishing mortality was divided across fleets (i.e. a target partial fishing mortality for each fleet is determined) using a historic quota share that was calculated from observed landings and, like catchability, can be assumed to be equal to the most recent quota share.

Assumptions about effort realisation were then made for all fleets (e.g. the "*min*" scenario in which the fleets stop fishing when they have used up their most limiting quota). Based on these scenarios, the effective effort per fleet was calculated. Once the efforts for all fleets were known under the different scenarios, the corresponding catches and future stock numbers were calculated. The difference between these realised catches and the TACs initially set showed the problems linked to technical interactions in mixed fisheries.

The version of the Fcube used before DRuMFISH (and currently used by the ICES MIXFISH working group) included two types of stocks which effectively contribute to the calculation of the effort per fleet in each mixed fisheries scenario: data-rich fish stocks with an analytical assessment, and *Nephrops* stocks with an assessment by video survey. For the data-rich stocks, available estimates of abundance/biomass and fishing mortality can be used to compute the effort (per fleet) corresponding to the TAC set, and to project the stock in a short term forecast. This is done using the classical age-structured stock dynamics in which the stock numbers are calculated as

$$N_{s,a+1,t+1} = N_{s,a,t}\ \mathrm{e}^{(-(F_{s,t}+M_{s,t}))}$$

Where $F_{s,t} = \sum_m F_{s,m,t}$ (with $F_{s,m,t}$ from previous equation) reflects the total fishing mortality summed across all métiers, and where $N_{s,a,t}$ reflects the stock numbers of a given stock *s*, for age *a*, and time *t*. $M_{s,t}$ reflects the natural mortality. The stock biomasses are then calculated from the stock numbers using the forecasted stock weights-at age.

[12] For more information on the sliding rule, see e.g. ICES (2016b)

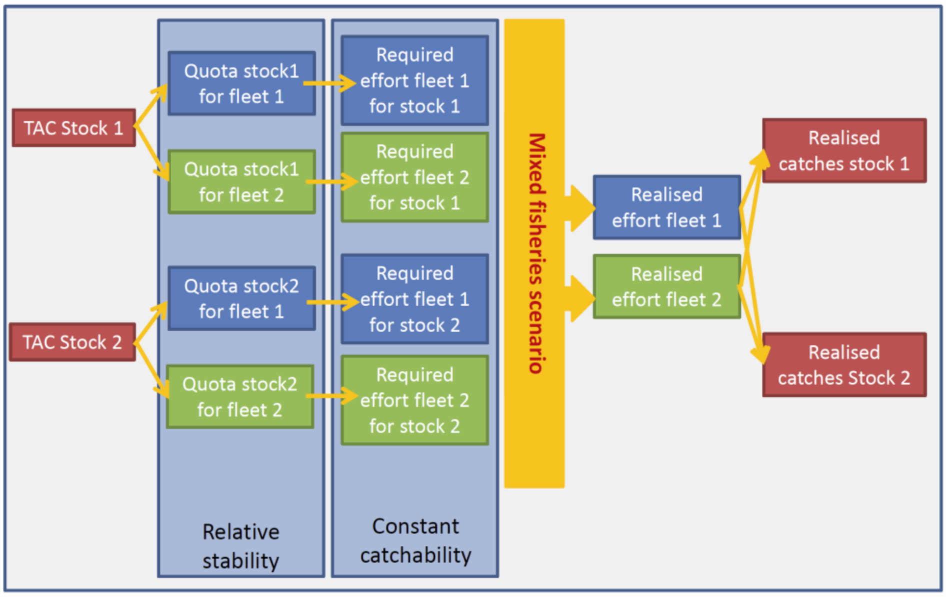

Figure 3.1 Summary of the Fcube methodology. Forecast for the catches resulting from the single-species TAC on the left hand seide of the figure are made using information on the recent activity of the fleets, and formulating assumptions on individual fleet effort deployment (i.e. "max", "min", and "status quo" scenarios).

The *Nephrops* stocks are shared in two groups. The category 1 stocks with TV-survey assessment and a short-term forecast contribute to the calculation of the effort per fleet in the TAC year, like the analytical fish stocks. But they do not include a feedback loop where a given effort level in the TAC year influences in return the abundance in the following year, and as such the *Nephrops* stocks cannot be included in medium-term MSE projections beyond the TAC year. The *Nephrops* stocks without a TV-survey based assessment (catch only stocks) do not influence the effort calculated for the fleets catching these stocks. Fcube simply considers that the CPUE for these stocks was constant and computed catches corresponding to the effort defined on the basis of the stocks for which an assessment was available. Thus, those stocks did not influence the outcome of Fcube.

Within the DRuMFISH project, the Fcube model was extended to include data-poor stocks using SPiCT assessment results. The stock biomasses and catches for data-poor stocks using SPiCT were computed differently from the data-rich stocks. In the case of the SPiCT stocks, stochastic biomass dynamics equations in SPiCT were used (see eq. 4 in Pedersen and Berg (2016)), rather than the age-structured dynamics. By using the forecasting functions that are available in the SPiCT implementation, we ensured that the dynamics estimated for the data–poor stocks in the assessments were correctly interpreted in the forecasts.

The inclusion of population dynamics for data-poor stocks meant that calculation of fleet fishing effort depended also on data-poor stocks. As a first step, the advice rule coded for SPiCT stocks was the ICES MSY advice rule. This rule was a proposal and not currently used by ICES, which continued to use the Data-Limited Stocks (DLS) approach (i.e. comparing mean over the last 2 years with mean over the 3 previous in an abundance index). Therefore, the advice was not strictly reproduced. However, these methodological developments were made in order to use Fcube in longer-term simulations, testing management strategies for data-poor stocks. It seemed that the ICES MSY rule was more in line with the management rules defined in the EU multi-annual plans for demersal mixed fisheries, based on F_{MSY} (and F_{MSY} ranges). Examples of the Fcube application with data-poor and data-rich stocks that were possible as a result of the DRuMFISH WP3 development can be found in the North Sea and Baltic Sea case studies.

FLBEIA: FLBEIA (Bio-Economic Impact Assessment using FLR) is a bio-economic simulation software, aimed at facilitating the evaluation of management strategies under the MSE approach (Garcia *et al.* 2017). The FLBEIA modelling framework was applied to several case studies (Bay of Biscay, Celtic Sea and North Sea). Conceptually, FLBEIA simulations are divided into two blocks: the Operating Model

(OM) and the Management Procedure (MP). The OM is the model part that simulates the true dynamics of the fishery system (the "true" populations). Stocks and fleets are its essential elements and they interact through fishing effort and catch. The MP describes the management process and is divided into three modules: the observation model (the link between the OM and the MP), the assessment procedure, and the management advice (Garcia *et al.* 2017). The observation model together with the assessment model generate the "perceived" population based on which the management advice is calculated. The advice is given in terms of catch and it can also be combined with technical management measures such as gear restrictions, temporal closures or capacity limitations.

FLBEIA already allowed for including age- and biomass-dynamic stocks within the simulation framework. Similar to Fcube, wrappers of a4a (Jardim *et al.* 2014) and SPiCT (Pedersen and Berg 2017) models have been developed and incorporated in the FLBEIA R package within DRuMFISH. As a result of the DRuMFISH project, data-poor stocks assessed using these models can be used within the management procedure to produce estimates of stock abundance and exploitation rate simulated in the Operating Model.

Currently, two approaches are available for using data-limited stocks in FLBEIA as a result of the DRuMFISH project. The first approach represent these stocks with age-structured operating models, using life history parameters available for the stock or borrowed from similar stocks in other areas. This was the procedure followed by Carruthers *et al.* (2014), which assumes several exploitation histories for the stock. If the existing uncertainty is taken into account this approach provides a good framework for testing data-poor management strategies based on age-structured populations. The second approach represents data-poor stocks with biomass-dynamic models such as SPiCT. The uncertainty on parameters estimated by the assessment is used to resample a large sets of model parameters, which are in turn used to reconstruct the corresponding time series of biomass and fishing mortality. This results in a set of populations, all representing a likely state of the stock at the start of the simulations, given the assessment uncertainty. These resampled parameters are also used to condition the biology of each replicate of the population in the simulations. The assessment uncertainty in the simulation is based on the uncertainty associated with the estimated biomass from SPiCT. More details and illustrations of this methodology are presented in Annex 7.

IAM: The IAM model was originally developed for the Bay of Biscay fisheries, with catches of the species other than hake and sole being modelled as a function of effort, assuming constant CPUE. Development of the simulation framework of IAM in the DRuMFISH project entailed the inclusion of population dynamics based on SPiCT assessment parameters available for anglerfish, similar to the other frameworks.

3.2. Mixed Fisheries Harvest Control Rules

Ultimately, the simulation frameworks should be used within e.g. STECF to identify options for mixed-fisheries Harvest Control Rules (HCRs). These HCRs aim to find combinations of target fishing mortality per stock within the established boundaries of F_{MSY} ranges. At present, no mixed-fisheries objectives exist, and therefore options presented are explorations of the range of possibilities. For example, for each of the three models referred above, HCRs have been explored as follows:

- In Fcube, the optimisation algorithm initially developed in the FP7 MYFISH project was further developed in the DRuMFISH project to find the combination of target fishing mortalities that minimises the risk of mixed-fisheries conflicts by minimising the differences between "min" and "max" options (Ulrich *et al.* 2017); maximising an objective function ("what's best") It identified a set of fishing mortalities per stock. This is different from the usual ("what if") setup of Fcube (Ulrich *et al.* 2017). The aim was to search the fishing mortalities for each stock within the F_{MSY} ranges that would minimize the mixed-fisheries imbalance. This "imbalance" is defined as the catch difference between the Fcube Min and Max options (measured as the sum across stocks of squared differences in total tonnes). Imbalance thus refers to mismatches between the various single-stock advice TACs. This mixed fisheries harvest control rule that minimizes the imbalance between single-species quota could thus be used for fisheries advice on quotas, adhering to advice that should be within F_{MSY} ranges.

This optimisation algorithm can be used to formulate a new type of mixed fisheries advice that ICES could deliver to support the implementation of a North Sea mixed fisheries MAP: advice can be given on the target fishing mortality and catch limits per stock. The current mixed fisheries advice only shows landings forecasts for the current management targets. The optimisation provides an objective method to set the F_{target} values within the authorised ranges, so that incompatibility between the resulting TACs are minimised. One of the objectives of doing this is to support the implementation of the landing obligation by reducing over-quota discarding. By minimising the difference between the "max" and the "min" Fcube scenarios, the optimisation procedure effectively minimises the incentive to continue fishing when the first quota is reached. In addition, the optimisation procedure can be used to quantify the potential costs and benefits of setting F target values for some stocks in the upper part of the F_{MSY} range. Based on this information, managers can decide whether it is justified to apply an F target between F_{MSY} and $F_{MSYupper}$.

- A multi-stock HCR was defined and incorporated to the FLBEIA library. This HCR produces simultaneous management advice for the stocks selected. The main aim of the HCR is to maximise fishing opportunities while ensuring sustainability of the stocks. To achieve it we imposed the following three restrictions:

1. Compatible catch advice

If we assume a linear relationship between fishing mortality and effort, with catchability (*q*), the proportionality parameter i.e. F = q x Effort. For compatible fishing mortality advice, it is enough to multiply the current fishing mortalities, i.e. the status quo fishing mortalities F_{sq}, by the same parameter, µ. Mathematically:

$$\mathrm{F}_{adv_s} = \mu \cdot \mathrm{F}_{sq_s}$$

Where *s* denotes the subscript for stock and F_{adv} the fishing mortality that will correspond with the TAC advice. The remaining problem is how to define µ to fulfil the second and third restrictions.

2. Uses most out of fishing opportunities

If the F_{adv} for all the stocks is equal or higher than the corresponding F_{MSY}, all the fishing opportunities corresponding with MSY framework will be used. Then, μ_0 is defined as:

$$\mathrm{Fadv}_{0,s} = \mu_0 \cdot \mathrm{F}_{sq_s} = \max_s \left(\frac{\mathrm{F}_{MSY_s}}{\mathrm{F}_{sq_s}} \right) \cdot \mathrm{F}_{sq_s}$$

A more conservative approach can be obtained using the mean instead of the maximum in the equation above, i.e.:

$$\mathrm{Fadv}_{0,s} = \mu_0 \cdot \mathrm{F}_{sq_s} = \mathrm{mean}_s \left(\frac{\mathrm{F}_{\mathrm{MSY}_s}}{\mathrm{F}_{sq_s}} \right) \cdot \mathrm{F}_{sq_s}$$

3. Compatible with MSY ranges

The F advice in the previous step could be higher than the upper bound of the fishing mortality range of some stocks. Hence, a second multiplier is applied to ensure that F_{adv} falls within the ranges for all the stocks, i.e.:

$$F_{adv_s} = \begin{cases} \mathrm{F}_{adv_{0,st}} = \mu_0 \cdot \mathrm{F}_{sq_s} & \text{if } \mu_0 \cdot \mathrm{F}_{sq_s} \leq F_{MSY\,upper_s} \text{ for all } s, \\ \mu_1 \cdot \mu_0 \cdot \mathrm{F}_{sq_s} = \min_{st} \left(\frac{\mathrm{F}_{MSY\,upper_s}}{\mathrm{F}_{adv_{0,s}}} \right) \cdot \mu_0 \cdot \mathrm{Fsq}_{st} & \text{if for any } s \;\; \mu_0 \cdot \mathrm{F}_{sq_{st}} > F_{MSY\,upper_s} \end{cases}.$$

where $F_{MSY\,upper}$ is the upper bound of the fishing mortality range.

In a TAC management system F_{adv_s} is translated afterwards in catch using the corresponding catch production function (i.e. Baranov catch equation).

4. Implementation of methodologies

Implementation of the different methodologies was carried out for 7 case studies: the Baltic Sea, the North Sea, the Celtic Sea, the Bay of Biscay, the Western Mediterranean, the Adriatic Sea, and the Aegean Sea (see Figure 4.1). Within the case studies, 35 data-poor stock assessments were done for different stocks. Each of the case studies explored future management for mixed fisheries using one or more simulation frameworks described in Chapter 3.

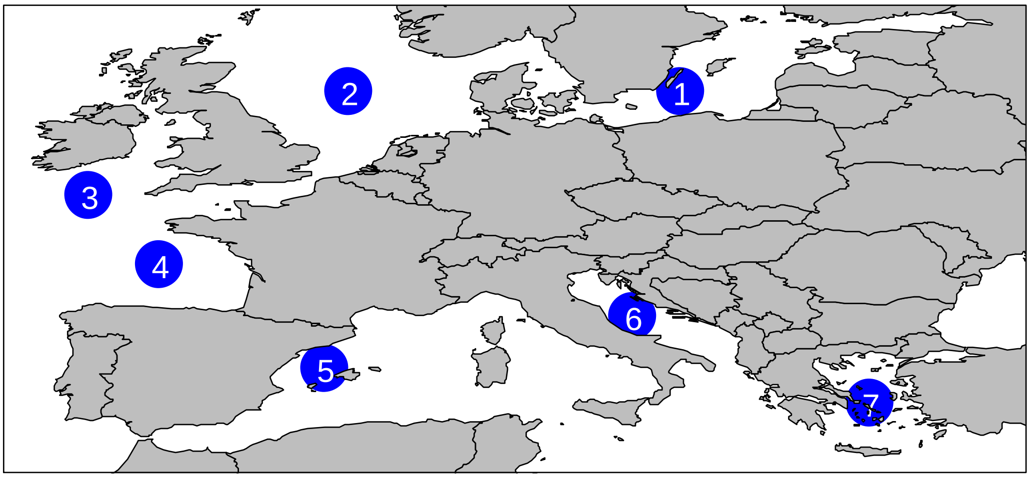

Figure 4.1 Map depicting the locations of the 7 case studies in the project: 1) the Baltic Sea, 2) the North Sea, 3) the Celtic Sea, 4) the Bay of Biscay, 5) the Western Mediterranean, 6) the Adriatic Sea, and 7) the Aegean Sea.

Data-poor assessments in the case studies

The choice of methods was determined by the nature of the data available and informed by the review carried out in the review work package (see Chapter 2). CMSY and SPiCT were used most across the case studies. For stocks with only catch data, CMSY was generally used. For stocks with catch data and abundance indices CMSY or SPiCT were used. The choice of SPiCT was linked to the increasing use of this model at ICES. In parallel to DRuMFISH, ICES initiated a process aiming at defining F_{MSY} proxies for most data-limited stocks. In many cases, SPiCT was chosen as the method for doing so. Many stock assessors in the North Sea, Baltic Sea and Celtic Sea ICES working groups were involved in DRuMFISH and to a large extent the ICES assessments were developed in DRuMFISH. The added value for DRuMFISH was that many SPiCT assessments were peer reviewed, and a decision was already made on their accuracy and usability to give advice. This led to the validation of SPiCT assessments for most of the stocks, but also to the rejection of the assessment for some of them (see also Table 4.2). For a number of stocks, the quality of the model was too poor to be accepted for use at ICES, as the estimated historical trajectories (biomass and fishing mortality) and reference points (F_{MSY}) were highly uncertain, and highly influenced by the choice of the data source used to fit the assessment model. Within the context of DRuMFISH, however, such assessments were used to give a broad idea of the dynamics of these stocks, and to allow for their incorporation in the mixed fisheries modelling. Therefore some of the assessments used in mixed fisheries simulations in the North Sea (anglerfish) or the Baltic Sea (flounder) case studies were not formally accepted at ICES.

Apart from these two main assessment methods, other approaches have been investigated, such as length based approaches, depletion models, or pseudo cohort analyses (principally in the West Mediterranean and Baltic Sea case studies). The aim was to test the usefulness of these data-limited methods by comparing their outcome with the outcome of data-rich (e.g. XSA) assessments available for these stocks.

Furthermore, the "Robin Hood" approach for data-poor stock was developed, consisting of building assessment models in which the information available from data-rich stocks is used to inform models on data-poor stocks. The first model has been developed for *Nephrops* stocks, in which estimates of population dynamics parameters from functional units with sufficient data were used to inform the parameter estimates for data-poor units. The second implementation of a "Robin Hood" approach is a joint assessment model for North Sea flatfish stocks. The model developed is a multi-species state-space model with F random walks correlated across each stock; in this way the data-rich species (sole and plaice) will inform the trend in mortality of data-poor species (e.g. turbot and brill) thereby leading to a more accurate estimate of the data-poor stocks, and their respective reference points. The method developed and the outcome of the North Sea application is presented in Annex 4.

Mixed fisheries modelling

Mixed fisheries short-term (2 years) forecasts were carried out for the Baltic Sea, North Sea and Celtic Sea using Fcube. Fcube is the mixed fisheries tool used by ICES to produce mixed fisheries advice in the North and Celtic Seas. With the methodological developments of Fcube in DRuMFISH, the dynamics of the data-limited stocks is now explicitly modelled, which allowed for projections of future stock dynamics, and therefore a more dynamic estimation of future catches and biomasses for all stocks. Therefore, with Fcube it is now possible to assess whether these data-limited species will be constraining fishing effort (acting as choke species[13]) of the fleets.

In order to test management strategies, the existing tool within Fcube used to carry out long term simulations was also further developed to incorporate the stocks assessed using SPiCT. This tool was used in the North Sea case study to test simple management rules: (i) TACs based on the ICES MSY advice rule for all stocks, (ii) TAC based on the ICES MSY rule for data-rich (target species) only, and (iii) TAC based on the use of the F_{MSY} ranges.

The FLBEIA framework is designed to carry out bio-economic evaluations of management strategies in a mixed fisheries context. FLBEIA has also been implemented for the Bay of Biscay and the North Sea case studies. The incorporation of the stocks assessed using SPiCT also required methodological developments which are presented in details in Annex 7.

Other methods have been chosen for the 3 Mediterranean case studies. The main impediment to the use of Fcube or FLBEIA approaches is the lack of detailed catch and effort information. For the Aegean

Table 4.1 Overview of the assessment models and mixed fisheries modelling approaches applied for each case study.

Case study	Types of data-rich assessment	Types of data-poor assessments	Mixed fishery modelling	Management rules tested
Data-rich dominated case studies				
Bay of Biscay	Age structured models	SPiCT A4A	FLBEIA (med-long term simulations)	Multi-species HCR in combination with ICES MSY rule
Celtic Sea	Age structured models	SPiCT	Fcube (short term forecast)	none
North Sea	Age structured models	SPiCT	FLBEIA Fcube (short term forecast) to be used within an MSE (medium to long-term projections)	ICES MSY rule, MSY rule for target species only (no TAC for data-limited TAC based on F_{MSY} ranges
Data-poor dominated case studies				
Adriatic Sea	NA	CMSY	Correlated trends in fishing mortality within CMSY	effort reduction
Aegean Sea	NA	SPiCT	simulation based on Pella-Tomlinson surplus production models (short and long term projections)	Effort control rules based on: -F_{MSY} -"pretty good yield" ranges -Precautionary approaches
Baltic Sea	Age structured models	SPiCT	Fcube (short term forecast)	none
Western Mediterranean	Age structured models	CMSY	MEFISTO, gear competition analysis	Management strategies based on effort regulation

[13] "A choke species is a species for which the available quota is exhausted (long) before the quotas are exhausted of (some of) the other species that are caught together in a (mixed) fishery" (Zimmermann *et al.* 2015).

Sea and Adriatic Sea case studies a similar approach to Fcube and FLBEIA was adopted, consisting of a small number of major fleet components (1 and 2 for the Adriatic and Aegean Seas, respectively) and partial fishing mortalities being proportional to fleets catch shares. The Aegean Sea used the SPiCT assessments with their uncertainties as a basis. The Adriatic sea used the CMSY assessments with their uncertainties as a basis. In the western Mediterranean Sea case study, the tool used was MEFISTO (MEditerranean Fisheries Simulation TOol). Table 4.1 gives an overview of the approaches applied for each case study. Table 4.2 gives the final list of stocks and assessment approaches chosen for each case study.

Main results across case studies

A detailed description of the outcome of the work of all case studies is given in the case study reports in Chapter 5. Here, we present here a synthesis of the main results in Table 4.2, showing the list of the assessments, stock status, and the main conclusions from the mixed-fisheries simulations.

Table 4.2 Overview of approaches within the different DRuMFISH case studies. F is the fishing mortality, F_{MSY} is the estimated fishing mortality at which maximum sustainable exploitation is achieved. B is the stock biomass, B_{MSY} is the expected biomass obtained when fishing mortality is at F_{MSY}. Question marks indicate that the fishing mortality or biomass in relation to relevant reference points is unknown. The "mixed fisheries simulations" column details the different simulations that were done within the different case studies and a short description of their outcomes. The "stocks in mixed fisheries simulations" column gives the stocks used in the mixed fisheries simulations, with data-limited stocks in bold.

Data-rich dominated case studies						
Case study	**Data-limited stock assessment**	**Current stock status**		**Assessment quality**	**Mixed fisheries simulations**	**Stocks in mixed fisheries simulations**
		F	**Biomass**			
Baltic Sea	Flounder (SPiCT[14])	$F<F_{MSY}$	$B> B_{MSY}$	Exploratory only	**Fcube: in the short term**, Western Baltic cod is the overall limitation for the fishing opportunities. However, due to the relative stability between EU Member States and the landing obligation in place for cod and plaice in the Baltic Sea, there is a risk that plaice will act as a choke species for cod, especially for Germany and Sweden. Inclusion of flounder did not alter the main outcomes.	Western Baltic cod, plaice, **flounder**
North Sea	Turbot (SPiCT) Brill (SPiCT) Dab (SPiCT) Flounder (SPiCT) Flounder (length based indicators) Lemon sole (SPiCT) Witch (SPiCT) Anglerfish (SPiCT) Thornback ray (SPiCT) Cuckoo ray (SPiCT)	$F<F_{MSY}$ $F<F_{MSY}$ $F<F_{MSY}$ F= ? $F<F_{MSY}$ $F<F_{MSY}$ $F<F_{MSY}$ $F>F_{MSY}$ $F<F_{MSY}$ $F<F_{MSY}$	$B> B_{MSY}$ $B> B_{MSY}$ $B> B_{MSY}$ B= ? $B> B_{MSY}$ $B> B_{MSY}$ $0.5 B_{MSY}<B< B_{MSY}$ $B> B_{MSY}$ $0.5 B_{MSY}<B< B_{MSY}$	Accepted by ICES in 2017 Accepted by ICES in 2017 Accepted by ICES in 2017 Poor model fit Accepted by ICES in 2017 Accepted by ICES in 2017 Exploratory only Exploratory only Exploratory only	**Fcube: in the short term**, data-limited stocks included are not likely to be choke species. **FLBEIA: medium term** simulations with stock management based on the MSY rule, and assuming a "min" mixed fisheries scenario show stable to positive trends in biomass (and SSB) among all stocks, and maintained F/F_{MSY} ratios < 1.0 during forecast years (2018-2021). Only whiting showed F/F_{MSY} > 1.0 for 2017.	cod, haddock, saithe, whiting, plaice, sole, **anglerfish, brill, dab, lemon sole**
Celtic Sea	Cuckoo ray (SPiCT) *Nephrops* (SPiCT) Black anglerfish (SPiCT) White anglerfish (SPiCT)	$F<F_{MSY}$ $F<F_{MSY}$ F= ? $F<F_{MSY}$	$B> B_{MSY}$ $B> B_{MSY}$ B= ? $B>= 0.5 B_{MSY}$	Assessment uncertain Poor model fit Poor model fit Good fit	**Fcube: in the short term** *Nephrops* did not appear limiting. Catching the full TAC for the *Nephrops* would lead to an increase of the fishing effort above the single-stock advice for the gadoid species.	cod, haddock, whiting, ***Nephrops***
Bay of Biscay	White anglerfish (SPiCT) White anglerfish (A4A[15]) Red mullet (SPiCT)	$F<F_{MSY}$ $F>F_{MSY}$ $F>F_{MSY}$	$B> B_{MSY}$ $B> B_{MSY}$ $B< 0.5 B_{MSY}$	Poor model fit Good model fit Acceptable model fit but B and F seem unrealistic	**FLBIEA & IAM:** Anglerfish is limiting the effort of fleets if TACs of data-poor stocks are set using the ICES MSY advice rule. This results in a decrease in quotas for these species, a loss of fishing opportunities for the other stocks, and a sharp decline in fleet profit. Under the	northern hake, megrim, **white anglerfish, red mullet**

[14] stochastic surplus production model in continuous time
[15] "Assessment for all" model

					current TAC setting approach (data-limited), the TAC for anglerfish was not limiting and there was a better use of quotas for other stocks. If the TACs of all stocks are set using the “multi-stock HCR” quota uptake improved if the underlying TAC setting approach is the ICES MSY rule (except for anglerfish, where the improvement was when management in based on the DLS approach). The “multi-stock HCR” produced higher profit for fleets when based on the ICES MSY advice rule.	
Data-limited dominated case studies						
	Data-limited stock assessment	**Current stock status**		**Assessment quality**	**Mixed fisheries simulations**	**Stocks in mixed fisheries simulations**
Western Mediterranean	Hake (CMSY[16]) Red mullet (CMSY) Hake (VIT[17]) Hake (LB-SPR[18]) Hake (MAGD[19])	**$F>F_{MSY}$** **$F>F_{MSY}$** **$F>F_{MSY}$** **F= ?** **F= ?**	**$B< 0.5\ B_{MSY}$** **$0.5\ B_{MSY}<B< B_{MSY}$** **$/B< 0.5\ B_{MSY}$** **B= ?** **B= ?**	All CMSY assessments are precise, but model sensitive to assumptions on depletion rates. Good agreement with XSA	**MEFISTO**: 9 scenarios of effort reduction were tested, from a 20% reduction over 5 years, as in the Spanish Mediterranean Fisheries Management Plan2013-2017 to an annual 30% reduction. Only this last scenario (leading to 83% effort decrease in 5 years) would result in all stocks exploited at less or close to the target F/F_{MSY} =1.	black anglerfish, hake, red shrimp, deep-water rose shrimp, **Greater forkbeard, megrim, white anglerfish, *Nephrops*, red mullet, striped red mullet**
Adriatic Sea	Great Mediterranean scallop (CMSY) Sole (CMSY) Cuttlefish (CMSY) Queen scallop (CMSY) Brill (CMSY) Murex (CMSY) Mantis shrimp (CMSY) Caramote prawn (CMSY)	**$F>F_{MSY}$** **$F>F_{MSY}$** **$F>F_{MSY}$** **$F>F_{MSY}$** **$F>F_{MSY}$** **$F<F_{MSY}$** **$F<F_{MSY}$** **$F<F_{MSY}$**	**$B< 0.5\ B_{MSY}$** **$0.5\ B_{MSY}<B< B_{MSY}$** **$0.5\ B_{MSY}<B< B_{MSY}$** **$B< 0.5\ B_{MSY}$** **$B< 0.5\ B_{MSY}$** **$B> B_{MSY}$** **$B> B_{MSY}$** **$B> B_{MSY}$**	Good model fit for all stocks, but model sensitive to assumptions on depletion rates	Projections run within **CMSY** assuming a unique effort multiplier for all stocks. Results show a recovery of most of the stocks by 2030 if fishing at 50% of the current effort except for Great Mediterranean scallop and brill because of their current very a low status. Their recovery would require additional management measures (e.g. spatial closures).	**Great Mediterranean scallop, sole, cuttlefish, queen scallop, brill, Murex, mantis shrimp, caramote prawn**

[16] Catch MSY model
[17] pseudo-cohort VPA model
[18] Length Based Spawning potential ratio
[19] Multi-Annual Generalized Depletion model

Aegean Sea	Hake (SPiCT) Red Mullet (SPiCT) Striped red mullet (SPiCT) Pink shrimp (SPiCT)	**$F>F_{MSY}$** **$F<F_{MSY}$** **$F<F_{MSY}$** **$F<F_{MSY}$**	**$0.5\ B_{MSY}<B<B_{MSY}$** **$B>B_{MSY}$** **$B>B_{MSY}$** **$B>B_{MSY}$**	Decent model fits for most stocks. Fit improved through the use of a prior value for the population growth rate, and interpolation of years with missing data in abundance indices	Under the current effort levels, the total yield from the fishery will be at 87% of the maximum multispecies yield but the hake stock will remain over-exploited, although not at a risk of collapse. Within this objective, to achieve maximum multispecies yield without extreme effort changes, the effort of the coastal fleet has to be reduced by 30%. “Pretty good yield” from all species can be obtained by different effort combinations, mainly involving increase of trawler effort and decrease of coastal fishery effort. Under this scenario, however, the hake stock will be severely overfished.	**Hake, Red Mullet, Striped red mullet, pink shrimp**

5. Case Study Reports

5.1. Baltic Sea case study

Executive summary

The Baltic Sea case study explored several stocks with SPiCT. Emphasis was given to developing a mixed fisheries model for Western Baltic cod and plaice in ICES subdivisions 21-23, that included flounder in ICES subdivision 22-23. The latter is a the data-poor stock that was assessed using SPiCT. The key outcomes of the Baltic Sea case study are:

- The first stock assessments using SPiCT have been conducted for several data-poor Baltic stocks.
- The assessments conducted under DRuMFISH have been presented to ICES WGBFAS and ICES WGNSSK but are not yet included in the assessments which these working groups produce.
- The main mixed fisheries issue regarding flounder is the risk of extensive discarding, which may continue as flounder is not subject to the landing obligation in the Baltic Sea.
- The mixed fisheries simulation for Western Baltic cod and plaice in subdivisions 21-23 suggest that Western Baltic cod is the overall limitation for fishing opportunities. However, due to the relative stability between EU Member States and the landing obligation in place for cod and plaice in the Baltic Sea, there is a risk that plaice acts as a choke species for cod, especially for Germany and Sweden.

Context

The Baltic Sea case study for mixed fisheries covered the Western Baltic Sea, including Kattegat and the Sound, comprised of ICES Subdivisions 21-24. There are a number of data-poor stocks in this region for which assessments methods have been tried within the DRuMFISH project (Figure 5.1).

The main species in the Baltic demersal fisheries are cod and a number of flatfish often caught as bycatch in the cod fisheries, including plaice and flounder. Accordingly, these stocks are important catches for these gears and for the métiers described below.

The case study covers the Danish, German and Swedish fleets in ICES subdivisions 21-24 (Figure 5.2). Due to the exploratory nature of the case study as well as limited data coverage for mixed fisheries in the area, a simple definition of fleets and métiers was chosen: fleets were defined by country and gear, where gear is divided into active or passive gears. Active and passive fleets were defined by gear type and constituted of the following fleet segments extracted from the ICES InterCatch[20] database:

- Active gears: “Active”, "Pelagic trawlers", "Trawl", "Bottom trawl", "Pelagic trawl", "BOT", "OTB_CRU_32-69_0_0_all", "OTB_CRU_32-69_2_22_all", "OTB_CRU_70-89_2_35_all", "OTB_CRU_90-119_0_0_all", "OTB_DEF_>=120_0_0_all", "Bottom trawl", "SSC_DEF_>=120_0_0_all"
- Passive gears: "Passive", "Gillnets set", "Longline set", "Passive gears", "Gillnet", "Trapnet" ,"GIL" , "GNS_DEF_all_0_0_all","FPO_CRU_0_0_0_all","GTR_DEF_all_0_0_all"

The métier classification was based on the division by gear type (active or passive) and area (ICES Subdivision) for the targeted species (cod, plaice and flounder). For each fleet this led to the following métier definition:

- Active gears: “Active_27.3.a.21”, “Active_27.3.c.22”, “Active_27.3.b.23”, “Active_27.3.d.24”
- Passive gears: “Passive_27.3.a.21”, “Passive _27.3.c.22”, “Passive _27.3.b.23”, “Passive_27.3.d.24”

[20] InterCatch is the database that contains all catch information held by ICES

Stock	Assessment method at the start of the project	Assessments developed within DRuMFISH
Cod 27.22-24	Cat1 (SAM assessment)	
Plaice 27.21-23	Cat1 (SAM assessment)	
Flounder 27.22-23	Cat3 (survey index)	SPiCT (accepted within ICES)
Brill 27.22-32	LBI/LBSPR	SPiCT (exploratory)
Turbot kask	LBI/LBSPR	SPiCT (exploratory)
Sprat kask	LBI/LBSPR	SPiCT (exploratory)
Dab 27.22-32	LBI/LBSPR	SPiCT (exploratory)
Whiting kask	LBI/LBSPR	SPiCT (exploratory)

Figure 5.1 Summary of the assessments developed within the DRuMFISH Baltic case study. "LBI": Length based indicator. "LBSPR": Length Based Spawner Per Recruit, see Hordyk et al. (2015).

Mixed fisheries occur in almost all of the above stated métiers/fisheries in the Baltic Sea. While trawling gears ("Active") may reduce unwanted bycatch of roundfish (like cod) or flatfish (like plaice and flounder) by targeting e.g. spawning aggregations or use specific fears with selective devices, the stationary gears ("Passive") usually cannot avoid mixed catch composition. Under the landing obligation 'choke species' may cause problems in those mixed fisheries. There are many examples for potential, perceived or real choke species under a landing obligation, and different ways to solve the problems arising from the bycatch of those for various fisheries. The Baltic Sea is the EU region where the landing obligation was introduced first, along with fisheries on pelagic species in all EU waters. Plaice serves as the example for a potential choke species in the Baltic Sea. Plaice is a quota species and discards regularly occur because some countries catch more than covered by their national quota while other countries lack a quota at all. The original intention of the introduction of a landing obligation in EU waters - to incentivise changes in fishing practices towards higher selectivity - appears to be at risk since Article 15 of the Basic Regulation (EU 2013) allows for several flexibilities of utilising quotas and a number of exemptions to the landing obligation. If widely applied, those rules may allow fisheries to continue with their present practices also under a formal landing obligation – which seems to be in clear conflict with the original objective of the approach.

Rationale for selection of fleets and species

The selection focused on cod, which is an important target species for the demersal fisheries in the Baltic Sea, on plaice, which is the only bycatch on the Baltic demersal fisheries targeting cod that is regulated by a TAC, and finally flounder, which is not regulated by a TAC but is commonly caught as bycatch together with plaice or cod, and which is a data-limited stock in the region.

No quantitative evaluations and analyses on mixed-fisheries issues involving data-poor stock assessments were done for the region prior to the DRuMFISH project.

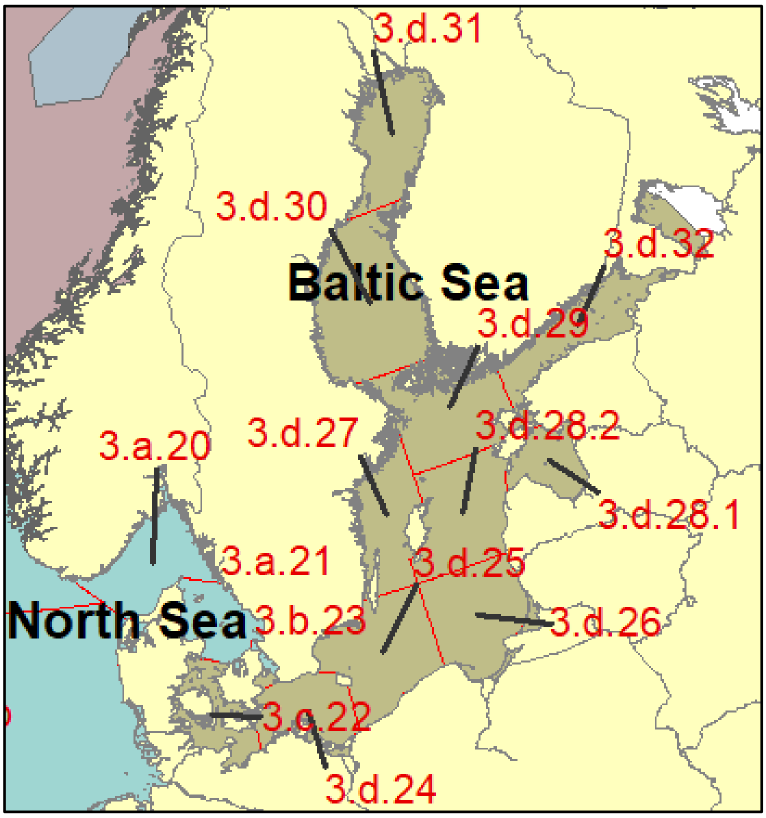

Figure 5.2 Overview of geographic areas included in the Baltic Sea case study. Adapted from www.ices.dk/marine-data/Documents/Maps/ICES-Ecoregions-hybrid-statistical-areas.png

Mixed fisheries issues

The fisheries for cod and plaice in the Baltic Sea are covered by the landing obligation, and plaice has been identified as a possible "choke species" for the Baltic fisheries targeting cod when discarding is prohibited (Zimmermann *et al.* 2015). As a whole, the plaice TAC does not seem to risk choking the cod fisheries. However, due to the relative stability in the distribution of the overall TAC between countries for plaice in the Baltic areas, there is a risk that the fisheries in certain Member States like Germany and Sweden will be choked by plaice (Figure 5.3), as reported previously (Zimmermann *et al.* 2015). The reason for this is that although the overall plaice TAC does not limit the fishing opportunities for cod under the current stock status of plaice and cod, the majority of the TAC shared for plaice is held by Denmark. Hence, limited quota for plaice remain for German and Swedish fishers. Thus, plaice may act as a Category 2 choke species, defined by the North Sea Advisory Council as:

*"**Category 2**: Sufficient quota at EU level, but insufficient quota at MS level—choke is due to a mis-match of catches and the distribution of quotas between Member States and can theoretically be resolved between themselves in a regional context."* (NSAC 2017)

This problem occurs especially for countries that do not have plaice (or cod) TAC. Latvia for example has a demersal fishery that takes place all year in the Eastern Baltic Sea (SD 25 and SD 26) with trawlers and gillnetters, targeting cod and flounder. The amount of Latvian plaice bycatch in sampled trips is highly variable, ranging between just a few kg to 12 t. But even these small amounts would cause a problem after the implementation of the landing obligation, because Latvia has zero plaice quota which would force Latvia to trade or buy quota from other countries (e.g. Denmark).

The inclusion of flounder in the mixed fisheries assessment does not point to a specific challenge for the demersal fisheries with respect to this species and stock. However, it is important to note that flounder is data-limited and the data for flounder in area 22 and 23 was only available in the ICES InterCatch data portal for 2016, meaning that the historical catches on which the scenarios could be based are very limited in time. Because flounder is not covered by a TAC in the Baltic Sea, the species

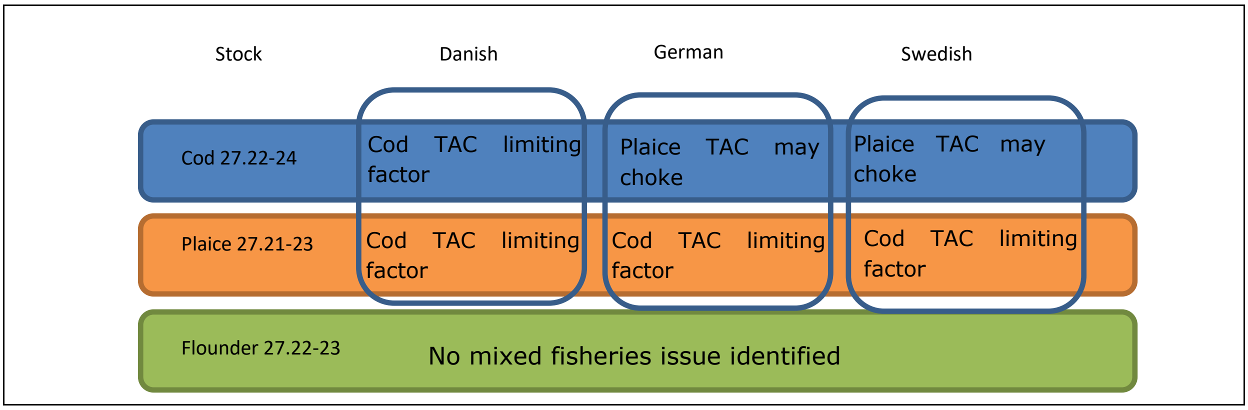

Figure 5.3 summary of the species in the mixed fisheries in the DRuMFISH Baltic case study.

is not subject to the landing obligation in the area (EU 2013) and, consequently, flounder is no choke species in the current management framework. Flounder catches are mainly taken as bycatch in the area (ICES 2017c) and as such the main mixed fisheries problem for the flounder stock in subdivision 22-23 is extensive discarding, particularly for active gears (ICES 2016a).

Choke-species problems can be mitigated by (i) a national redistribution of quotas or by (ii) international quota swaps, especially if the overall availability of TACs is sufficient as seems to be the case with plaice in the Baltic. Among the changes in fishing practices in the original spirit of the landing obligation are (i) the use of gear with an improved selectivity and (ii) spatio-temporal avoidance of unwanted bycatch.

Stock Assessments

The SPiCT model was developed mainly within this case study, in cooperation with ICES WKLIFE V, ICES WKPROXY, ICES WGNSSK, ICES WGBFAS, and ICESCat34. The focus was to develop this model by application for the selected stocks in the Baltic Case Study. Relative or absolute estimates of spawning stock biomass and fishing mortality, and MSY reference points were obtained by applying SPiCT. These result were brought forward to ICES assessment working groups.

The data-poor stock assessments made associated to DRuMFISH are presented in Figure 5.1. There, the main activities and results are presented in term of data-poor assessments developed during the project. This includes tabulation of the initial status, the justification of the methods (data), and their level of implementation. Note that this list consists of more species than those in the used in the final Fcube simulation framework.

Data input for the SPiCT assessment of flounder in subdivisions 22 and 23 comprise of landings from 2002 – 2016 and biomass tuning indices 2002-2016 from the BITS surveys index Q1 and Q4 based on weight.

Main results from the stock assessments

Figure 5.4 presents the historical development and status of flounder in ICES subdivision 22-23. The biomass for this stock appears to have increased since 2005, in response to a decreas in fishing mortality. Fishing mortality is below FMSY for the last 10 years.

Assessments for the data-poor stocks have been presented to ICES WGBFAS and ICES WGNSSK assessment working groups. So far the uncertainty and robustness is not at a level were these SPiCT assessments have been accepted by the working groups.

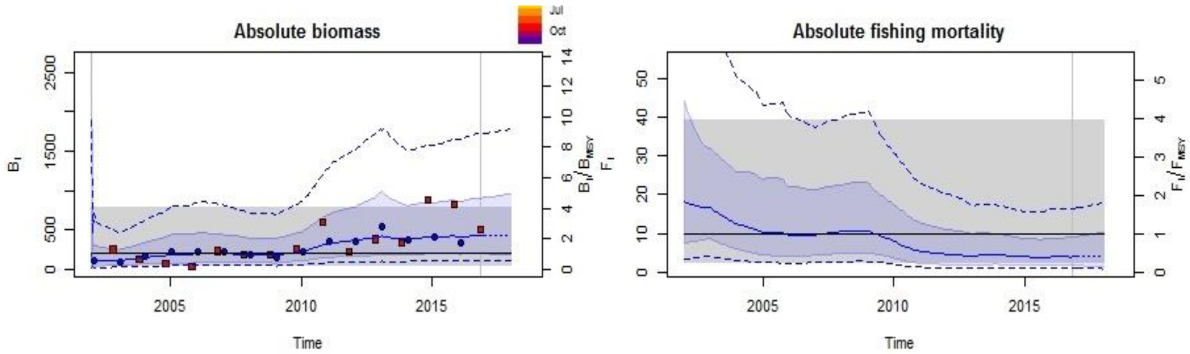

Figure 5.4 SPiCT summary for flounder in ICES subdivisions 22-23. These include biomass (left) and fishing mortality (right), including the relevant reference points (B_{MSY} and F_{MSY}).

Mixed fisheries modelling

The final mixed fisheries modelling included plaice, Western Baltic cod and flounder. Plaice and Western Baltic cod are data-rich stocks, for which assessments were already available. Flounder is a data-poor stock assessed within DRuMFISH (Table 5.1).

Western Baltic cod in ICES subdivision 22-23 and plaice in ICES subdivision 21-23 are governed by a TAC and are both subject to the landing obligation (ICES 2017a, 2017b, 2017d). Flounder in ICES subdivision 22-23 is not regulated by a TAC (ICES 2017c), meaning that flounder is not subject to the landing obligation. Bycatch of flounder is taken into account in the EU Multiannual Plan for the Baltic Sea (EU 2016) as flounder is commonly caught as bycatch together with plaice or cod.

Fcube was used to evaluate the discrepancy between the single-stock advice for the main stocks and the catches that are likely to be taken under mixed fisheries interactions (Ulrich *et al.* 2011). Fcube uses catch and effort data on a fleet basis to estimate the effort corresponding to each of the single-stock advice set for each species caught by each fleet. The term “fleet’s stock share” or “stock share” is used to describe the share of the fishing opportunities of a stock for each particular fleet in 2018, assuming that the proportion of catches by fleet for that stock in 2017 and 2018 is the same as observed in 2016. Assumptions on effort realization are made (e.g. the “min” scenario where for each fleet, fishing effort in 2018 stops when the most limiting of the stock shares of that fleet has been caught). Based on these scenarios, the resulting effort per fleet and the corresponding catches were calculated. The difference between these realised catches and the single-stock advice showed the problems linked to technical interactions in mixed fisheries.

The data compilation procedure used for Fcube was as follows:

- Assessment data for cod and plaice was extracted from http://stockassessment.org.
- ICES Single-stock advices for 2018 were translated into forecast.
- Data on catch and effort per year, area, country, stock, fleet and métier was extracted from the ICES InterCatch data portal for German, Danish and Swedish vessels operating in ICES subdivisions 21-24. Data for both plaice and cod was available from 2012. Data for flounder was available from 2016. Fleets and métiers by country were divided into active and passive gears.
- The commercial catches of Western Baltic cod in ICES subdivision 24 from the InterCatch data was corrected for the share of the Eastern Baltic cod stock overlapping with the Western Baltic cod stock in ICES subdivision 24 based on the fractional correction stated in the ICES Latest Advice sheet for Western Baltic cod (ICES 2017b). Additionally, a fleet segment was created to incorporate the recreational catch share of cod in the Western Baltic, assuming that recreational fisheries retain all catches. Effort for the German recreational catches on Western Baltic cod was set to a fixed value of 100 days at-sea. Recreational catches for Western Baltic cod were estimated to comprise approximately one third of the total catches of Western Baltic cod.

Table 5.1 Mixed fisheries case study stocks evaluated in Fcube with SpiCT.

Stock	ICES Stock data category	Simulation model	Geographical distribution
Plaice 27.21-23	1	Fcube with SAM	ICES SD 21-23
Cod 27.22-24 (Western Baltic cod)	1	Fcube with SAM	ICES SD 22-24
Flounder 27.22-23	3	Fcube with SPiCT	ICES SD 22-23

The following mixed-fisheries scenarios for Western Baltic cod and plaice in subdivisions 21-23 were tested:

- "Max": For each fleet, fishing effort in 2018 stopped when all stock shares of that fleet have been caught up. This option causes overfishing of the single-stock advice possibilities of most stocks.
- "Min": For each fleet, fishing effort in 2018 stopped when the most limiting of the stock shares of that fleet has been caught up. This option is the most precautionary option, causing underutilization of the single-stock advice possibilities of other stocks. This scenario can highlight some potential "choke species" issues.
- "Status quo effort": The effort of each fleet in 2017 and 2018 was set equal to the effort in the most recently recorded year for which landings and discard data are available (2016).
- "Plaice 27.21-23": All fleets set their effort in 2017 and 2018 corresponding to their plaice stock share, regardless of other catches. Note that there were differences in the plaice catches between this scenario and the single-stock advice because of the slightly different forecast methods used.
- "Cod 27.22-24": All fleets set their effort in 2017 and 2018 corresponding to their cod stock share, regardless of other catches. Note that there are differences in the cod catches between this scenario and the single-stock advice because of the slightly different forecast methods used.

In the "min", "max", and "status quo effort" scenarios, effort in the intermediate year (2017) was assumed to be equal to its 2016 level. In the cod.27.22-24 scenario, effort in the intermediate year (2017) was assumed to be reduced by the catch constraint (-55%), consistently with the assumptions in the ICES single-stock forecast.

Fcube focused primarily on risks of over-quota catches and increased discards when the overall single-stock advice is limiting for one stock (Ulrich *et al.* 2011). This means that the scenarios presented are only investigating towards the effects of MSY-based advice, but do not assume any quota balancing through changes in targeting behavior (i.e. changes in catchability and/or in effort distribution) and/or changes in access to quota. This can thus somehow differ from the Landing Obligation scenarios described in e.g. Zimmermann *et al.* (2015), where distributional issues linked to the relative stability in a fully-enforced landing obligation scenario can play a major role in the choke species issue, e.g. when one country has high discards because of quota limitations but not the other country.

The Fcube with SPiCT scenarios for Western Baltic cod, plaice in subdivisions 21-23 and flounder in subdivisions 22-23 had the same scenarios tested as the Fcube run without SPiCT but with the inclusion of the flounder stock, using the F_{MSY} target as a single-stock advice for that stock since flounder is not regulated by a TAC in the area.

Main results and conclusions

The comparison of the 2018 single-stock advice for cod and plaice in the Western Baltic displayed some major discrepancies between the two stocks, with the cod advice calling for major reductions in fishing mortality both in 2017 and 2018, while for plaice a slight increase was foreseen (Figure 5.5). This indicates that cod advice is very restrictive for most fleets.

Indeed, the results of the mixed-fisheries scenarios showed that it was not possible to achieve F_{MSY} simultaneously for both stocks under the current fishing patterns (Figure 5.6). If decreasing the fishing mortality for cod was the major objective and fleets would stop fishing after exhaustion of their cod share, the catch share for plaice in the mixed fisheries may not be fully utilized.

The 2018 cod advice is estimated to be limiting for 8 fleets representing 68% of the 2016 effort, while plaice is estimated to be limited for one fleet (32% of the effort). Altogether, the effort would have to be decreased by 76% compared to 2016 if the “min” scenario was applied.

Similar results were obtained when including flounder, and assuming that fleets could increase their effort up to the level corresponding to the flounder F_{MSY} objective. Flounder was estimated to be exploited below F_{MSY} (~40% F_{MSY}) when the max scenario was driven by this very high target (Figure 5.7). Cod would still be the most limiting stock in 2018.

When considering MSY objective only (as in the single-stock advice), it is clear that plaice in the Western Baltic is currently exploited more sustainably than cod, and the latest advice allows for increase in both catches and fishing mortality for plaice. As such, cod is the major choke species in this fishery in 2018.

Considerations are not given here on the issues linked to actual distribution of the plaice quota across Member States when plaice becomes integrated in the landing obligation. It has been well identified that issues are likely to arise due to major differences in catch patterns across countries (Zimmermann *et al.* 2015), and new model developments are necessary to integrate these distributional issues in the mixed-fisheries modelling. These developments are currently ongoing as part of the work performed by the ICES WGMIXFISH group.

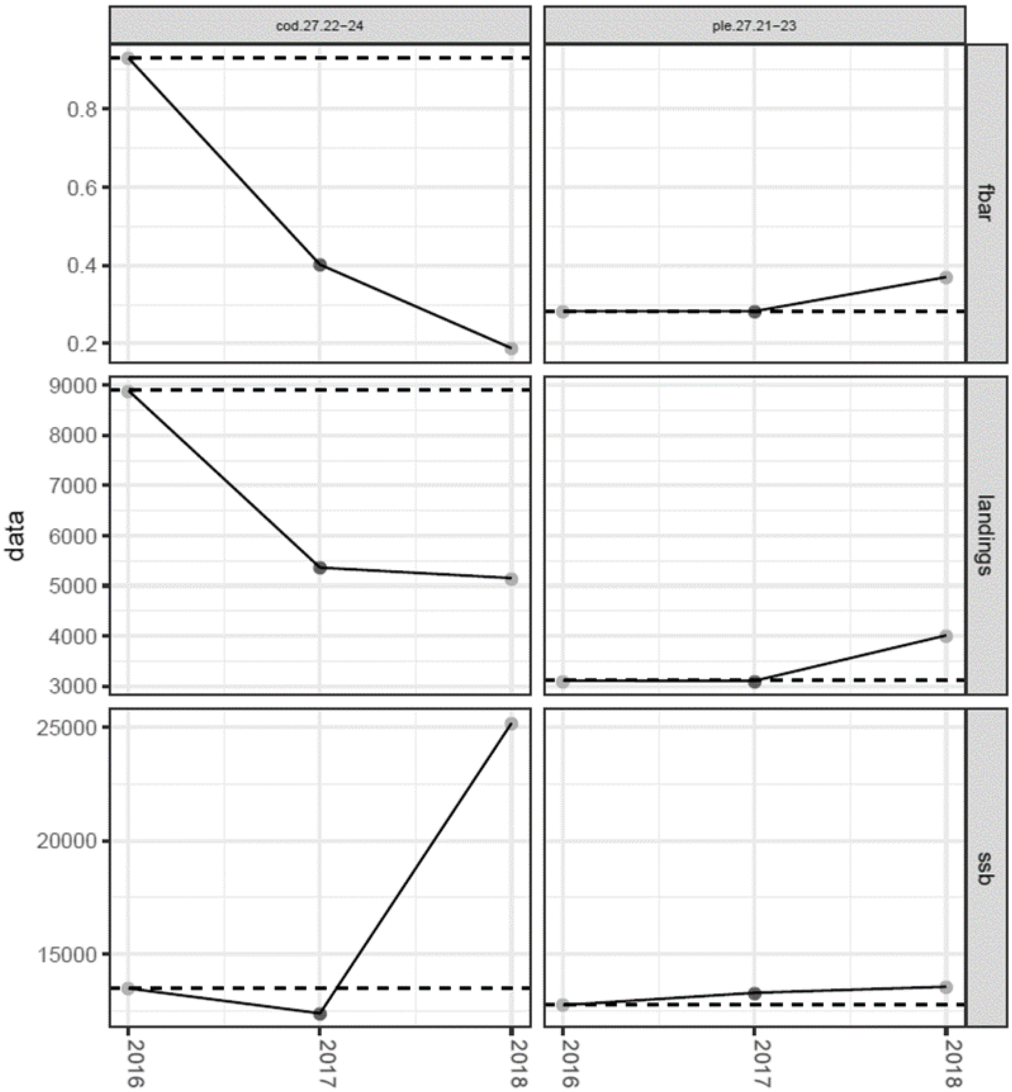

Figure 5.5 Single-stock short-term forecast as reproduced in Fcube. Changes in F (top panels), landings (wanted catch; middle panels) and SSB (bottom panels) by stock in last assessment year (2016), intermediate year (2017) and advice year (2018). The horizontal dashed line indictes the 2016 baseline level in each of the panels.

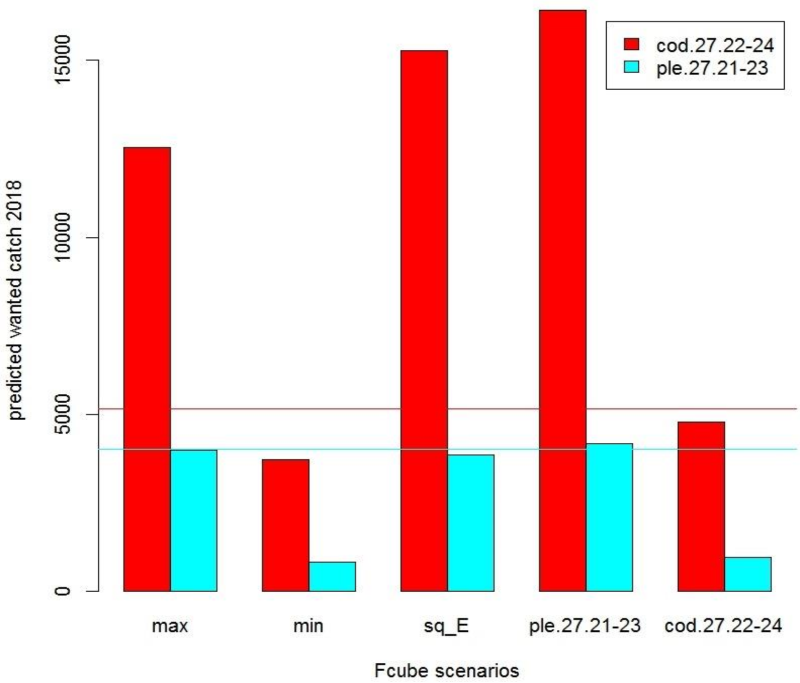

Figure 5.6 Western Baltic mixed-fisheries projections. Estimates of potential catches (in tonnes) by stock and scenario. Horizontal lines correspond to single-stock catch advice for 2018. Vertical bars below the horizontal line of the same colour show undershoot (compared to single-stock advice) where catches are predicted to be lower when applying the scenario. Vertical bars being above the horizontal line of the same colour represent catches that overshoot the single-stock advice.

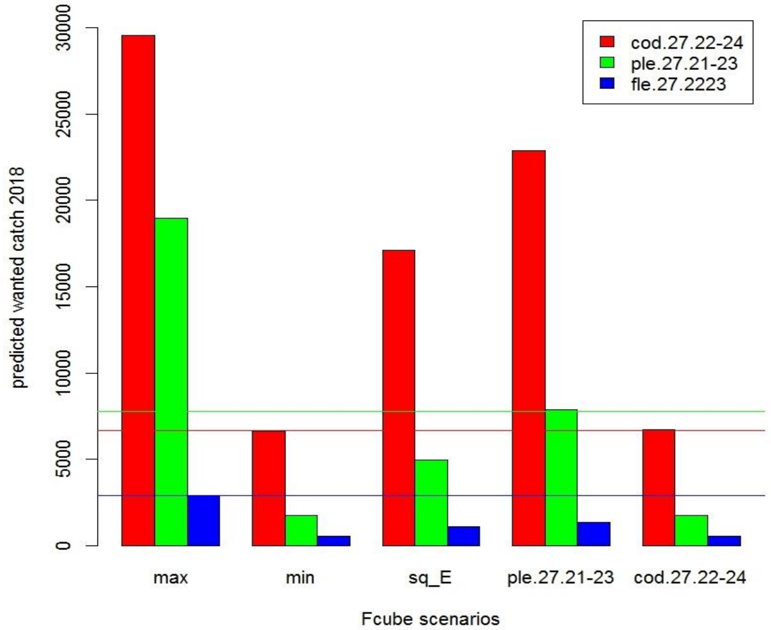

Figure 5.7 Western Baltic mixed-fisheries projections including flounder. Estimates of potential catches (in tonnes) by stock and scenario. Horizontal lines correspond to single-stock catch advice for 2018. Vertical bars being below the horizontal line of the same color show undershoot (compared to single-stock advice) where catches are predicted to be lower when applying the scenario. Vertical bars being above the horizontal line of the same color represent catches that overshoot the single-stock advice.

5.2. North Sea case study

Executive summary

DRuMFISH applied up to date data-poor assessment methods to all data-poor stocks in the greater North Sea that were under TAC management at the start of DRuMFISH (i.e. turbot, brill, lemon sole, witch, dab, flounder, and anglerfish). In addition, exploratory assessments were carried out for elasmobranchs and *Nephrops* stocks. Although the fish stocks in the case study had an index based category 3 assessment at the start of the DRuMFISH project, reference points were missing for all of them. DRuMFISH applied SPiCT (Stochastic Surplus Production model in Continuous Time) as main the assessment method. This method allowed assessments and reference points to be developed in a consistent manner. In addition, model estimates from SPiCT could be used to condition mixed fisheries simulations. In those cases where SPiCT was not able to fit the available time series with sufficient quality, length based indicators were applied.

It was possible to test SPiCT assessments for all stocks in the case study during DRuMFISH. Exploratory SPiCT assessments were directly forwarded to the relevant ICES assessment working groups. The SPiCT assessments for dab, witch, lemon sole, turbot, and brill were used by ICES to determine stock status. For flounder length based indicators were used due to unacceptably high uncertainty in reference points estimated by SPiCT. For anglerfish a benchmark is scheduled for the near future and the decision on reference points was postponed. The 2017 advice for elasmobranchs in the case study did not make use of information on stock status.

Based on the SPiCT assessments all stocks with reference points agreed by ICES (dab, flounder, brill, turbot, lemon sole, witch) are currently not overfished and above biomass thresholds. The exploratory DRuMFISH assessment for anglerfish indicated that the stock was slightly overfished in 2015 in relation to a potential F_{MSY} proxy, while the exploratory assessments for turbot in 3a and thornback ray suggested that these stocks are currently not being overfished and above potential biomass thresholds. Cuckoo ray was also not overfished according to an exploratory SPiCT assessment, but the current biomass was below potential biomass thresholds.

Mixed fisheries simulations were carried out in DRuMFISH with both Fcube and FLBEIA for the North Sea. Important improvements were achieved during DRuMFISH. Fcube now accommodates data-poor stock dynamics in medium- to long-term simulations and the choke effects of DLS stocks can be detected for mixed fisheries advice. The same is possible with FLBEIA with this method being applied to the North Sea mixed fisheries for the first time.

The first Fcube run conducted in DRuMFISH with 4 data-poor stocks indicated that the likely choke species (on the basis of the data used for the 2016 advice) are data-rich stocks (haddock and sole), while the data-limited stocks required higher fishing efforts for their quotas to be filled (anglerfish and brill).

Long term simulations in Fcube indicated that this situation was likely to continue, with haddock appearing consistently as a choke species in the future. In a situation where these data-limited stocks are not targeted (i.e. quota not necessarily fished), almost all stocks appeared to be managed within precautionary levels. Simulations also indicate that with the current level of effort, all stocks should remain within safe biological limits, exploited close to F_{MSY}, with future landings similar or larger than current levels. Likewise, the FLBIEA implementation also indicated no strong choke effects from the additional species in the simulations under F_{MSY} management.

Based on DRuMFISH work, more data-poor stocks will be included in ICES WGMIXFISH and mixed fisheries advice in the near future. To this end, several models were set up to test specific management strategies and to give advice on mixed fisheries management options.

Context

The case study focused on ICES areas 4 (North Sea) as well as 3a (Skagerrak and Kattegat) and 7d (Eastern English Channel)(Figure 5.8). Dependent on the stock definition some stocks are present only in parts of the three areas (e.g. turbot in subarea 4), for some stocks the stock area is larger (e.g. anglerfish in Subareas 4 and 6 and Division 3a).

The case study focused on the following stocks:

- Turbot in North Sea
- Brill in North Sea, Skagerrak and Kattegat, English Channel
- Dab in North Sea, Skagerrak and Kattegat
- Flounder in North Sea, Skagerrak and Kattegat
- Lemon sole in North Sea, Skagerrak and Kattegat, Eastern English Channel
- Turbot in Skagerrak and Kattegat
- Witch in North Sea, Skagerrak and Kattegat, Eastern English Channel
- Anglerfish (*Lophius piscatorius* and *L. budegassa*) in North Sea, Rockall and West of Scotland, Skagerrak and Kattegat
- Hake (Northern stock) in Greater North Sea, Celtic Seas, Northern Bay of Biscay
- Cuckoo ray in 4 and 3a; Thornback ray in 4, 3a and 7d; *Nephrops* in subarea 4 (FU 6,7,8 and 9)

Rationale for selection of fleets and stocks

The case study focused on the main demersal fleets operating in the North Sea. There are more than 100 fleet-métier combinations (country*area*vessel length category*gear*mesh size) used for mixed fisheries modelling with Fcube and FLBEIA in this case study. However, overall two main demersal fisheries with beam trawls (TBB) can be distinguished in the North Sea. The TBB_CRU fishery for brown shrimp (*Crangon crangon*) and the fishery for plaice and sole (TBB_DEF). Otter trawls (OTB) are used to fish for *Nephrops* (OTB_CRU). Larger meshed otter trawls and demersal seines (SSC) mainly target demersal fish species (cod, haddock, whiting, saithe, plaice; OTB/SSC_DEF). Next to this there is a fishery with passive gears targeting mainly cod, plaice and sole but also anglerfish in deeper areas. Figure 5.9 highlights which fisheries are responsible for the main catch of data-poor stocks included in the case study. By-catch of certain species also occurs in fisheries that are not highlighted, but they are minor compared to the marked ones.

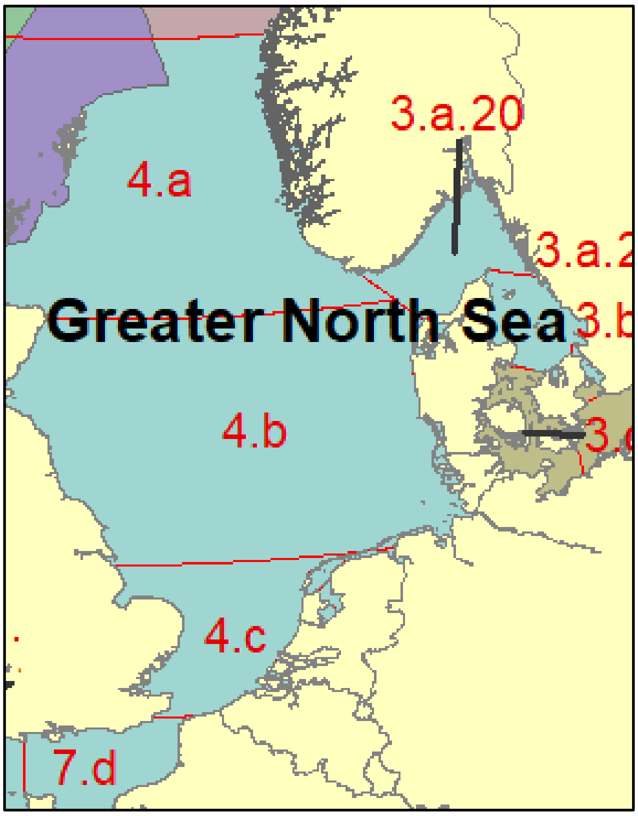

Figure 5.8 Overview of geographic areas included in the North Sea case study. Adapted from www.ices.dk/marine-data/Documents/Maps/ICES-Ecoregions-hybrid-statistical-areas.png.

The stocks are demersal data-poor stocks that are managed by TAC in the greater North Sea and are therefore potential choke species under the landing obligation. The selection included anglerfish and hake as stocks with a stock distribution wider than the TAC area, flatfish stocks that are managed by a combined TACs as well as vulnerable elasmobranchs. In addition, *Nephrops* was included as example of an important shellfish species because currently the *Nephrops* stocks are assumed to be constant in time in long-term mixed fisheries simulations for this species due to difficulties in forecasting stock dynamics. Overall, the selection ensures that various challenges regarding mixed fisheries management in the greater North Sea are addressed. All fleet-métier combinations used by ICES WGMIXFISH to provide mixed fisheries advice for the greater North Sea were included in the mixed fisheries simulations.

Mixed fisheries issues

Within the case study the main problem is the mixed nature of demersal fisheries in the North Sea and therefore the choke species problem under the landing obligation is highly relevant. Mixed fisheries predictions show that the choke species problem may lead to a substantial loss of fishing opportunities from less vulnerable stocks.

Stock assessments

At the start of the DRuMFISH project, dab, flounder, lemon sole, turbot in 3a and witch were assessed using IBTS survey indices as category 3 assessments (Figure 5.10). For brill the assessment was based on a commercial Dutch LPUE index. Turbot in Subarea 4 was assessed with an analytical age-based SAM model. However, the quality of the assessment was not sufficient for category 1 advice. Therefore, it was treated as category 3 assessment and the advice is based on the trend in estimated SSB. Anglerfish had a category 3 assessment based on an anglerfish survey in subarea 6 and division 4a. For cuckoo ray and thornback ray assessments based on survey indices were available. *Nephrops* in functional units 6, 7, 8, and 9 were assessed using underwater TV surveys.

Although all stocks in the case study had at least an index based category 3 assessment at the start of DRuMFISH, reference points were missing for all stocks apart from *Nephrops* in FU 6, 7, 8, and 9. DRuMFISH investigated whether production models could be used to forecast *Nephrops* stock dynamics for long-term mixed fisheries simulations. For all other stocks DRuMFISH focused on the development of methods to assess and derive reference points. Reference points are most important. Without reference points the status of stock remains unknown, reducing the effectiveness of assessments and increasing the risk of overexploiting data-poor stocks.

The main assessment method used was SPiCT. This method allowed the use of available information from catch and survey time series. Stocks can be assessed and reference points can be determined in a consistent way with SPiCT. In addition, model estimates from SPiCT could be used to condition mixed fisheries simulations (see Chapter 3). In cases where SPiCT was not able to fit the available time series with sufficient quality, length based methods were applied (e.g. length based indicators for flounder in 4 and 3a). These methods use the length frequencies from catch data as input.

Main results from the stock assessments

SPiCT assessments for all case study stocks were developed during DRuMFISH (Figure 5.10). Exploratory SPiCT assessments were forwarded to the relevant ICES assessment working groups. The SPiCT assessments for dab, witch, lemon sole, turbot in 4, and brill were used by ICES to determine stock status. For flounder length based indicators were eventually used. For anglerfish a benchmark is scheduled in the near future and the decision on reference points was postponed. The 2017 advice for elasmobranchs did not make use of information on stock status.

Based on the available SPiCT assessments, all stocks with proxy reference points agreed by ICES are not overfished in relation to the F_{MSY} proxy and are above biomass thresholds (Table 4.2, Table 5.2). The exploratory SPiCT assessments (

Table 5.3) indicated that anglerfish was slightly overfished (relative to the F_{MSY} proxy) in 2015, while turbot in 3a and thornback ray were not overfished (relative to the F_{MSY} proxy) and above potential biomass thresholds. Cuckoo ray was also not overfished

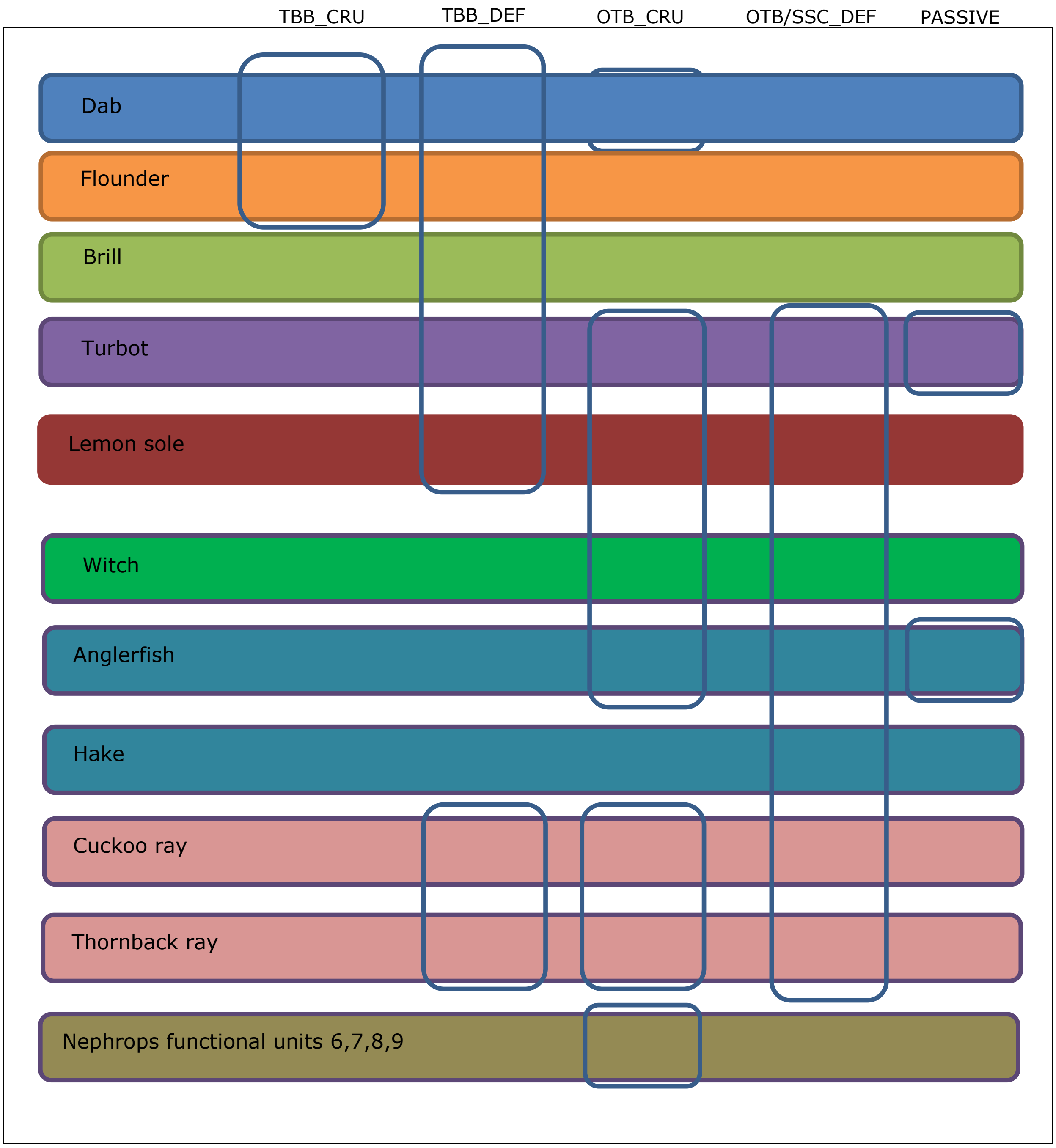

Figure 5.9 Mixed fisheries interactions with data-poor stocks in the main demersal fisheries of the North Sea. Blue frames indicate which stocks were caught by the different fleets. By-catches of certain species also occurs in fisheries that are not highlighted by a blue frame, but they are minor compared to the marked ones.

(relative to the F_{MSY} proxy) according to an exploratory SPiCT assessment, but the current biomass was below potential biomass thresholds. In Annex 1 the SPiCT standard graphs are available for all SPiCT assessments.

In general, the experience gained during DRuMFISH also shows the large uncertainties around model estimates and sensitivity towards the choice of input data. Sensitivities were found in relation to the data source (ICES or STECF or FAO), the length of the catch and index time series, stock definition, and to some extent the model settings. Therefore, the determination of stock status for data-poor

Stock	Assessment method at the start of the project	Assessments developed within DRuMFISH
Dab	Cat3 (survey index)	SURBAR + SPiCT
Flounder	Cat3 (survey index)	SPiCT + LBI
Brill	Cat3 (LPUE index)	SPiCT
Turbot in IV	Cat3 (SSB index SAM assessment)	SPiCT
Turbot in IIIa	Cat3 (survey index)	SPiCT
Lemon sole	Cat3 (survey index)	SPiCT
Witch	Cat3 (survey index)	SPiCT
Anglerfish	Cat3 (survey index)	SPiCT
Hake	Cat1 (SS3 assessment)	
Cuckoo ray	Cat3 (survey index)	SPiCT
Thornback ray	Cat3 (survey index)	SPiCT
Nephrops	Cat1 (UWTV index)	SPiCT

Figure 5.10 Summary of data-poor assessments available and developed in the North Sea case study during the project.

stocks remains difficult and uncertain, even when using advanced models like SPiCT. What has also been found is that sometimes, stock trends and catches develop in a way that challenges the simplifying assumptions of a more aggregated model such as SPiCT, which combines several processes into a reduced set of parameters. For example, for most of the *Nephrops* stocks, the catch is declining along with the stock abundance; in contrast, a production model assumes that with declining catches the stock will recover. This highlights that production models like SPiCT cannot handle situations where processes like recruitment or natural mortality become more important for stock development compared to fishing mortality. In such situations, any longer-term forecast based on a production model must be misleading.

Mixed fisheries modelling

Management targets have been available for the main target stocks in the North Sea for a number of years. Those targets are based on F_{MSY}. However, for data-poor stocks no reference points were defined before DRuMFISH. In DRuMFISH, assessments and reference point estimations have been carried out. Those estimations were used within ICES to set reference points for a large number of data-poor stocks in 2017.

The main management measures in the North Sea are TACs. The effort limits from the last cod management plan were still present but will likely be abandoned in the near future. In addition, there were technical regulations (MCRS, mesh size regulations, area and time closures). The landing obligation was being introduced step wise between 2016 and 2019. A new mixed fisheries management plan was under negotiation.

Table 5.2 Status of stocks with reference points agreed by ICES. F is the fishing mortality, F_{MSY} is the estimated fishing mortality at which maximum sustainable exploitation is achieved. B is the stock biomass, B_{MSY} is the expected biomass obatained when fishing mortality is at F_{MSY}. The column "B≥0.5BMSY" thus asks if the biomass in the most recent year was larger than 50% of B_{MSY}.

Stock	Assessment method	$F \leq F_{MSY}$	$B \geq 0.5B_{MSY}$
Turbot in North Sea	SPiCT, agreed by ICES WGNSSK 2017	Yes	Yes
Brill in North Sea, Skagerrak and Kattegat, English Channel	SPiCT, agreed by ICES WGNSSK 2017	Yes	Yes
Dab in North Sea, Skagerrak and Kattegat	SPiCT, agreed by ICES WGNSSK 2017	Yes	Yes
Flounder in North Sea, Skagerrak and Kattegat	No acceptable SPiCT assessment possible with current data. Length based indicators suggest that the stock is not overexploited. Benchmark planned for 2018.	Yes	?
Lemon sole in North Sea, Skagerrak and Kattegat, Eastern English Channel	SPiCT, agreed by ICES WGNSSK 2017. Benchmark planned for 2018	Yes	Yes
Witch in North Sea, Skagerrak and Kattegat, Eastern English Channel	SPiCT, agreed by ICES WGNSSK 2017. Benchmark planned for 2018	Yes	Yes

Table 5.3 Results from exploratory SPiCT assessments. F is the fishing mortality, F_{MSY} is the estimated fishing mortality at which maximum sustainable exploitation is achieved. B is the stock biomass, B_{MSY} is the expected biomass obatained when fishing mortality is at F_{MSY}. The column "$B \geq 0.5\ B_{MSY}$" thus asks if the biomass in the most recent year was larger than 50% of B_{MSY}.

Stock	Assessment method	$F \leq F_{MSY}$	$B \geq 0.5\ B_{MSY}$
Anglerfish in North Sea, Rockall and West of Scotland, Skagerrak and Kattegat	Exploratory SPiCT assessment during DRuMFISH. Benchmark planned for 2018	No	Yes
Turbot in Skagerrak and Kattegat	Exploratory SPiCT assessment during DRuMFISH	Yes	Yes
Thornback ray (*Raja clavata*) in IV, IIIa and VIId	Exploratory SPiCT assessment during DRuMFISH	Yes	Yes
Cuckoo ray (*Leucoraja naevus*) in IV, IIIa and VIId	Exploratory SPiCT assessment during DRuMFISH	Yes	No

The mixed fisheries modelling could draw from catch and effort data for all main fleets/métiers available from ICES WGMIXFISH and STECF. Data are available for the period 2003 – 2016. Discard data for data-poor stocks were available from ICES for the most recent years only. STECF data were available since 2003. Problematic were discard data on elasmobranchs: the total catch was unknown to ICES and also STECF estimates were highly uncertain if available at all.

Both Fcube and FLBEIA were parameterized using the ICES single-stock advice groups' data (landings, discards (at age when necessary and available) and results of the assessment models) as well as effort and landings data from ICES WGMIXFISH. ICES WGMIXFISH was already parameterised for the eight main stocks in the North Sea and eastern English Channel for which the group provides advice yearly (cod, haddock, plaice, sole, saithe and whiting). DRuMFISH allowed for development of routines to provide inputs for the data-limited stocks to be included in both Fcube and FLBEIA. These data are mostly coming from the ICES InterCatch database and the ICES WGMIXFISH data base. InterCatch provides the landings and discards data when available for the single-species advice and ICES WGMIXFISH database provides landings with the associated effort by métiers (some of these data were collected and made available to ICES during the DRuMFISH project). Age disaggregated data were made available to the DRuMFISH project by merging the age disaggregated data from InterCatch and the WGMIXFISH data bases.

Before the DRuMFISH project, some of the data-limited stocks[21] were already included in Fcube, but they did not influence the calculation of the effort in the different mixed fisheries scenarios. Short-term projections of the catches for these stocks were based on the effort of the fleets (calculated by taking into account only the data-rich stocks) multiplied by the catch-per-unit-effort for the data-limited ones, assumed constant.

The development of new SPiCT assessments for a number of data-limited North Sea stocks within DRuMFISH (see section 3) made it possible to include these stocks in Fcube in the same manner as the data-rich stocks. With the methodological developments in Fcube made during DRuMFISH, the dynamics of the data-limited stocks are now explicitly modelled, which allows for a projections of future stock dynamics, and therefore a more dynamic estimation of the future catches and resulting biomasses for these stocks. In addition, since a fishing mortality is now available for these stocks, they are now included in the calculation of the effort in the different mixed-fisheries scenarios. Therefore, with Fcube it is now possible to assess whether these data-limited species will be constraining the effort (acting as choke species or the opposite) for some fleets in the North Sea.

Next to Fcube as modelling platform, FLBEIA has been parameterized for the North Sea mixed fisheries. The FLBEIA modelling framework can simulate both fully age-structured dynamics for data-rich stocks (COD-NS, HAD, PLE-EC, PLE-NS, POK, SOL-EC, SOL-NS, WHG-NS) and biomass dynamics for data-poor stocks. Anglerfish was chosen as a test case because it is a key data-poor stock, requested by ICES for inclusion in future WGMIXFISH advice reporting.

For data-poor stocks, results from surplus production models (i.e. Pella-Tomlinson type) estimated through SPiCT assessments (see section 3) could be directly integrated into the FLBEIA framework. Model parameters used to govern biomass dynamics (intrinsic growth rate *r*, carrying capacity *K*, production curve shape *n*) were used to forecast future production, while estimated historical biomass and catches are used to estimate surplus production values $(gB(t_1) = B(t_2) - B(t_1) + C(t_1)$ and, subsequently, catchability between the stock and the various fleet/métiers. Although not used in this initial forecast, stochasticity in dynamics may be introduced from the resulting covariance matrix of parameter residual error.

In contrast to the mixed fisheries forecasts currently used by WGMIXFISH with Fcube, FLBEIA employed age-structured dynamics at both the stock and fleet/métier levels, resulting in age-structured selectivity patterns. Historical catches at age (landings and discards numbers and mean weights) allowed for the estimation of fishing mortality (F) at age for all fleet/métier/stock combinations. Combined with effort (f) at the fleet/métier level, catchability quotients (q = F/f) were derived for all historical years and kept constant in the simulations. In addition, the fate of historical catches as either landings or discards was specified by a selectivity parameter (i.e. ratio) by age. Given the substantial differences in InterCatch data quality and coverage, only 2016 was used to inform future fishing selectivities due for completeness and being most representative of fishing selectivities. Effort allocation between métiers for a given fleet was constant and future quota shares per fleet were equal to their share of the catches in 2016.

MSE based on Fcube

The simulation model built around Fcube was used to carry out stochastic long term simulations for the 8 data-rich stocks and 4 data-limited stocks (anglerfish, brill, dab and lemon sole). The detailed description of the configuration for these simulations is given in Annex 3. For the data-rich stocks, the stochastic processes are limited to recruitment variability. All iterations (replicates of the stock) have the same starting conditions (equal to the assessment output), but each have different recruitment variations in the simulated period. For the SPiCT stocks, the projections in the future were done within the framework of the SPiCT model. There was no stochasticity in the stock dynamics (as model parameters representative of the population dynamics remain constant over time within SPiCT). There was however different starting conditions for each iteration, thereby introducing some

[21] Brill, dab, flounder, hake, lemon sole, red mullet, turbot, and witch

variability in the simulations. Three management strategies for the North Sea mixed fisheries were tested:

Scenario 1 - MSY management for all stocks: in this scenario, both data-rich and data-limited stocks were managed using TAC which are calculated based on the ICES MSY advice rule.

Scenario 2 – MSY management of the target species only: in this scenario, only the data-rich stocks were managed using TACs which are based on the ICES MSY rule. There was no management of the data-limited stocks. This scenarios follows the philosophy of the EU multi-annual plans, in which by-catch species are supposed to be appropriately management by a TAC system on the target species alone.

Scenario 3 – MSY range management for all stocks: this scenario aimed at reducing the imbalance between single-species TACs for species caught in mixed fisheries. The idea is to artificially reduce the TAC for the least limiting species (pulling the effort of the fleets up) in the mixed fisheries, by using the lower bound of the F_{MSY} range as target instead of the F_{MSY} point estimate. The upper bound of the range is used for the most limiting species (limiting the effort of the fleets). An ad hoc method to determine for which species the upper or lower bound of the range should be used (instead of running Fcube) consisted in deciding to use the upper bound instead of the point estimate for stocks which are currently exploited at $F > FMSY_{upper}$, and using the lower bound for stocks that are currently exploited at $F < FMSY_{lower}$.

Those three management strategies were implemented for each of the three Fcube scenarios ("min", "max" or "status quo").

MSE based on FLBEIA.
For age-structured stocks, a segmented regression stock-recruitment relationship (SRR) was fit to recruitment and spawning stock biomass data since 1995. This time span restriction was used to account for differences in spawning success related to possible climate regime changes. Similar approaches have been used within benchmark assessments among many species in the North Sea.

The forecasts assume perfect observation and assessment of stock size, and thus focus is placed on the identification of choke species rather than on applying a full MSE.

A single, medium-term forecast of 5 years was simulated, where the harvest control rule was to calculate TACs based on F_{MSY}, and to implement fishing closures when the first stock reaches its prescribed TAC ("min" scenario). Fishing closure occurs at the fleet level when the share of a certain TAC has been reached. TACs values for the intermediate year were provided by ICES advice reports, while future TAC were based on the ICES harvest control rule for data rich stocks, which moderates F_{MSY} based on B_{lim} and $B_{trigger}$ reference points. The data-poor stock used a similar HCR rule, which aims for SPiCT-derived F_{MSY}, but limits yearly changes in catches to +/- 10% of the previous year.

Main results and conclusions
The Fcube test run including data-limited stocks for the North Sea made during DRuMFISH included 4 data-limited stocks (anglerfish, brill, dab and lemon sole), for which catch and effort data per fleet were available. For anglerfish no ICES approved SPiCT assessment was available. Therefore, the results are only indicative and may change after further benchmarks. Figure 5.11 and Figure 5.12 show the estimated potential landings for 3 mixed fisheries scenarios from the Fcube run including these stocks, compared to the landings corresponding to the single-stock advice for 2017. A full presentation of the methods and the results is given in Annex 2.

The results indicate the same limiting stocks (scenario "min") as the Fcube run made by the 2016 ICES MIXFISH ADVICE working group, namely haddock and to a lesser extent Eastern Channel sole. Therefore, none of the data-limited stocks included are likely to act as a choke species. On the contrary, Fcube projections indicate that catching the full TAC for anglerfish and brill (scenario "max") would imply a substantial increase of effort compared to the status quo effort situation, and would result in catches exceeding the ICES advice for most of the stocks. If the effort does not change compared to recent years ("status quo" scenario), there would be a large overshoot of the haddock and Eastern channel sole TACs, and an underutilization of the FU6-9 TACs for *Nephrops*, Eastern channel plaice and saithe for the target species, and anglerfish, brill and lemon sole for the data-limited species.

It should be noted that among the 4 data-limited stocks included in this Fcube run, the ICES catch advice has been increasing in the recent years for 3 of them and that these stocks are considered in a good state (based on the SPiCT assessments). It was therefore not likely that these 4 stocks would act as choke species.

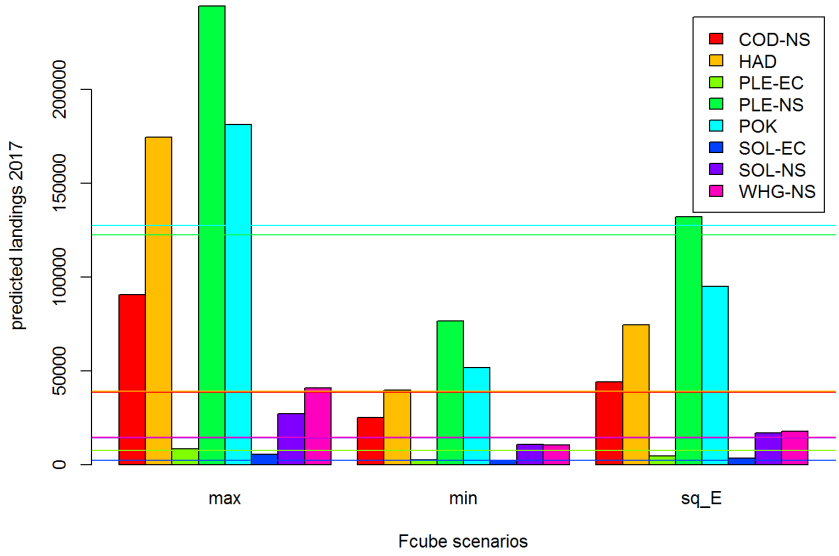

Figure 5.11 Fcube estimates of potential landings (in tonnes) by stock and by scenario for the stocks with analytical assessments. Horizontal lines are landings corresponding to the single-stock catch advice for 2017. "max" is the scenario in which fleets continue to fish until their last quota is takem, "min" is the scenario in which the fleets stop fishing as soon as their first quota is taken, "status quo" is the scenario in which the effort of each fleet in 2016 and 2017 is equal to the effort in 2015.

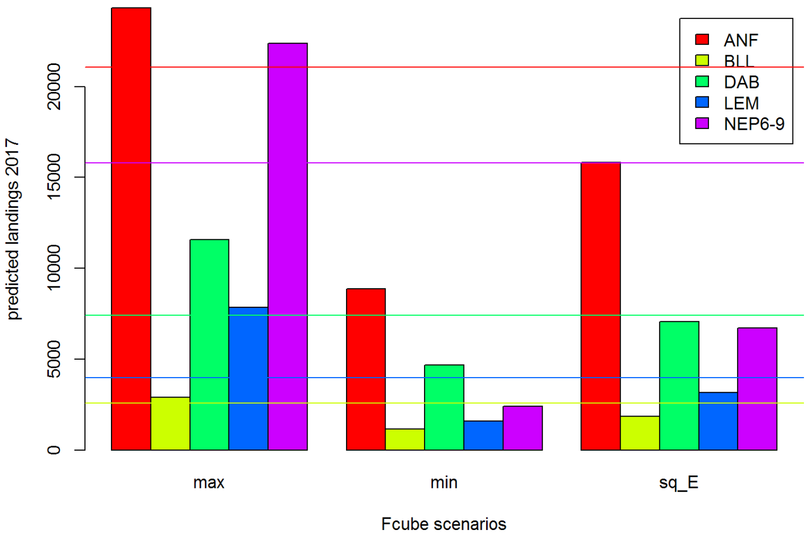

Figure 5.12 Fcube estimates of potential landings (in tonnes) by stock and by scenario for the Nephrops stocks and the stocks assessed with SPiCT. Horizontal lines are landings corresponding to the single-stock catch advice for 2017 . "max" is the scenario in which fleets continue to fish until their last quota is takem, "min" is the scenario in which the fleets stop fishing as soon as their first quota is taken, "status quo" is the scenario in which the effort of each fleet in 2016 and 2017 is equal to the effort in 2015.

Long term simulations based on Fcube

In the current state of the North Sea mixed fisheries, haddock appears to be the main choke species, and simulations show that it should remain so in the long-term even if the magnitude of the choke effect will decrease with time. Therefore, in a situation where fleets are not allowed to over-catch any of their quota, and given that haddock represents such a strong bottleneck, the different mixed fisheries strategies implemented here have the same performance (since all 3 had the same basis for advice for haddock). Simulations showed (in the "max" scenario) that catching the quotas for the data-limited stocks would require the highest effort for the fleets. However, since those species are not main target species for most fleets, it is unlikely that there would be a strong incentive for the fleet to increase their effort to fulfil these quotas (Table 5.4). Assuming that these species are mainly by-catch species, and setting TACs only for the main target species, simulations suggest that, even in a situation where fleets overshoot some of their quotas ("max" scenario), most stocks should remain within safe biological limits, and an increase in the landings is expected. Finally, simulations show that the current level of effort would result in stocks within safe biological limits in the future, exploited at levels close to F_{MSY} and with landings similar or larger than current levels.

Table 5.4 Comparison of the performance of the three management strategies tested for the three Fcube scenarios: "min", "max" and "status quo". In the "min" scenario fishing stops once the first quota is reached, for each fleet, in each year. In the "max" scenario fishing stops when all quotas are reached, for each fleet, in each year. In the "status quo" scenario fishing effort in the future is equal to 2015 effort. For the "min" and "status quo" scenarios results for the three different management strategies are similar, and the decriptions span the three management strategy columns. For the "max" scenario the "TAC based on FMSY only for data rich stocks" strategy differs from the other two strategies.

Fcube scenario	management strategy		
	TAC based on F_{MSY} all stocks	**TAC based on using the F_{MSY} ranges all stocks**	**TAC based on F_{MSY} only for data rich stocks**
"min"	No difference in the performance of the management strategies as haddock is consistently limiting the effort of most of the fleets and for the three strategies the advice on haddock has the same basis (F_{MSY}). Low fishing mortality, all stocks within safe biological limits and large stock size. Future landings lower than current levels for anglerfish, brill, lemon sole, plaice, at similar levels for saithe, dab and cod, and at higher level in the medium and long term for haddock and sole)		
"max"	Effort determined by data-limited stocks. Extremely high fishing mortality and high risk for the stocks. Landings decreasing compared to current levels except for haddock and saithe		Effort determined by saithe quota. Fishing mortality higher than F_{MSY}, but precautionary for most stocks. Higher landings than current levels
"status quo"	No influence of management, most stocks within safe biological limits, exploited close to F_{MSY}, future landings similar or larger than current levels.		

FLBEIA - The "min" scenario allowed for stable to positive trends in biomass (and SSB) among all stocks, and maintained F/F_{MSY} ratios < 1.0 during forecast years (2018-2021). Only North Sea whiting showed F/F_{MSY} > 1.0 for the intermediate year (2017, F/F_{MSY} = 1.12).

The "min" scenario performed as expected, with fishing closures occurring at the fleet level once a single-stock's TAC was fulfilled. Overall, the haddock TAC (HAD) was nearly fished out in the intermediate year, 2017, while the TACs for other stocks were often substantially underutilised. In subsequent forecast years (2018-2021) the North Sea sole (SOL-NS) TAC was exhausted nearly completely. In all years, early closures at the level of the different fleets prevented complete fulfilment of TAC even for haddock and North Sea sole (i.e. Landings/TAC ratio < 1.0), although missing portions were typically less than 5%: HAD (2017) = 0.96, SOL-NS (2018) = 0.98, SOL-NS (2019) = 0.96, SOL-NS (2020) = 0.94, SOL-NS (2021) = 0.96.

The single data-poor stock, ANF, was found to be a choke species in only 2 of the 43 fleets (SC_Otter<10 (2017 only), SC_Otter<24 (post-2017)). This result must be viewed cautiously given that reference points derived from the SPiCT assessment and the assessment itself have not been officially agreed. Although not included in this initial exploration, the addition of the remaining SPiCT stocks are not expected to be greatly limiting given that their good stock status as reflected by F/F_{MSY} and B/MSY $B_{trigger}$ ratios greater or smaller than 1 respectively.

5.3. Celtic Sea case study

Executive summary

The Celtic Sea case study attempted to develop analytical assessments for the regional stocks of *Nephrops*, cuckoo rays and anglerfish. *Nephrops* is considered by ICES as a category 1 assessment prior DRuMFISH as it directly relies on underwater TV surveys but lacks of a proper analytical assessment. Cuckoo rays and black and white anglerfish are trend based assessment (ICES category 3). Those stocks share in common the management issues of having a combined TAC between different species (rays, anglerfish) or between areas with distinct contrasted abundances (*Nephrops*). Cuckoo rays and black and white anglerfishes. Cuckoo rays and anglerfish also share the fact their assessment relies on several surveys with inconsistent survey indices because of mismatch of survey coverage or because of the lack of sufficient individual caught.

None of the assessments tested reached an operational stage despite the assessment method SPiCT being increasingly used within the ICES community. A *Nephrops* assessment however has been progressively implemented in Fcube as an exploratory run within the ICES mixed fisheries working group (WGMIXFISH). An exploratory assessment has been carried out for the white anglerfish stock using SPiCT and exploratory implementation is being done within Fcube. Cuckoo rays stock assessment revealed to be too noisy to be usable

In terms of outcome from the assessment, both *Nephrops* and white anglerfish assessment suggest those species are slightly above B_{MSY} and slightly below F_{MSY}. However those results are associated with very high uncertainties. The Cuckoo ray stock is the most data-rich stock among rays and skates. Despite this, it was impossible to develop some analytical assessment. The problem is related to the noisy signal from the survey indices and this is a bad signal in regards to the potentials of developing assessments for the other "data-poorer" stocks of rays and skates.

A mixed fisheries simulation was only reached for *Nephrops* included with cod, haddock and whiting. *Nephrops* did not appear limiting but fishing effort may be driven above the single-stock advice for the gadoid species. Some issues appeared in the implementation of *Nephrops* related to the current TAC management. For *Nephrops*, an overall TAC for subarea 7 is given regardless of the contrast of abundance within the Functional Units which requires making hypothesis on some TAC split between FUs accordingly to the local status of the *Nephrops* in each FU. A similar problem appeared for cuckoo rays and anglerfish stocks as their respective TACs are combined for several species expand and coverage wider areas than the Celtic Sea. The management of mixed fisheries in the Celtic Sea would be improved if TACs were allocated at the same scale as available information in terms of species and spatial definition of the stock. An important point in the context of the Fcube scenarios carried out within the ICES WGMIXFISH is that Fcube is sensitive to the assumption made to derive a TAC for all these species. In terms of future development, while the data are clearly deficient for the cuckoo ray, implementation of anglerfish stocks into Fcube will probably benefit from the outcome of the work done for *Nephrops*.

Context

The Celtic Seas comprise the shelf area west of Scotland (ICES Subarea VIa), the Irish Sea (VIIa), west of Ireland (VIIb), as well as the Celtic Sea proper (VIIf-k) and western Channel (VIIe) (Figure 5.13). The variety of habitats in the Celtic Sea accommodates a diverse range of fish, crustacean and cephalopod species that support a wide variety of fisheries targeting different species assemblages.

Celtic Sea demersal fisheries are characterised by a large number of data-poor stocks with economic and ecosystem importance (e.g. anglerfishes, megrim, skates and rays). Around 62% (39 of 63) of stocks for which ICES gives advice in the Celtic Seas eco-region are currently considered data-poor, while the highly varied fish community and mixed nature of the demersal fisheries mean there are also several stocks of economic importance (e.g. john dory, lemon sole, turbot and brill) for which no advice is available at all. Several stocks have full analytical assessment such as cod, whiting and

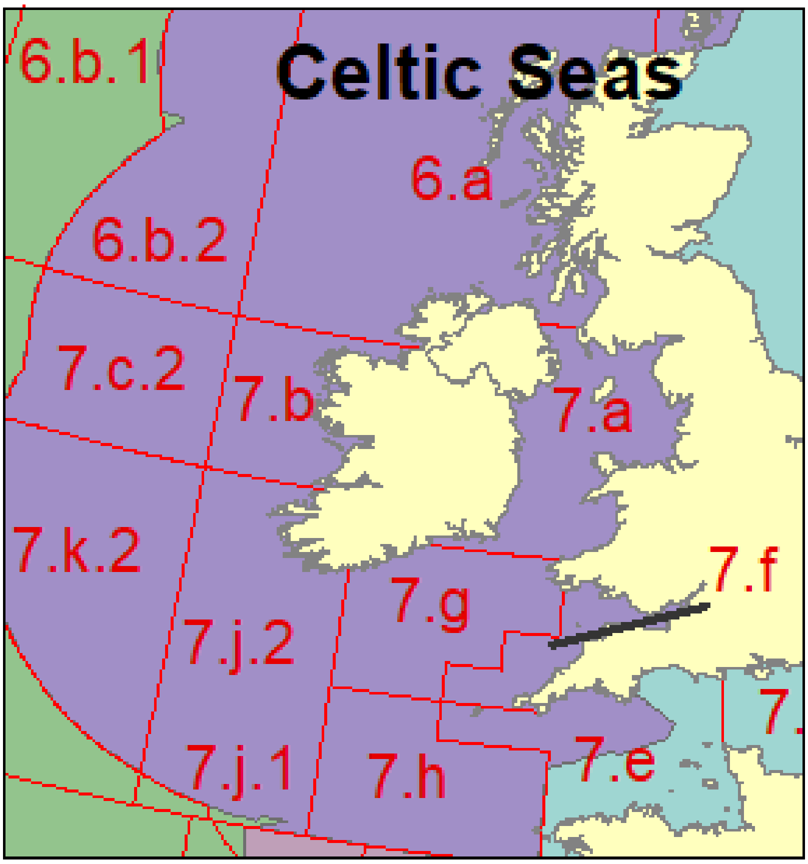

Figure 5.13 Overview of geographic areas included in the Celtic Seas case study. Adapted from www.ices.dk/marine-data/Documents/Maps/ICES-Ecoregions-hybrid-statistical-areas.png

haddock, some stocks of sole and plaice. Some other stocks have only trend based assessment (e.g. anglerfish) and for other including sensible species (e.g. elasmobranchs), no assessment or trends are available. Mixed fisheries modelling frameworks have so far included only data-rich stocks which for the Celtic sea were mainly gadoid stocks (cod, haddock, and whiting). Attempts to include some stocks of sole and plaice have been carried out. A recurrent issue with those attempts is the geographical mismatch between the stock definitions of main gadoid stocks and those additional smaller stocks which generally become choke species in terms of management.

This ecoregion has important commercial fisheries for cod, haddock, whiting and a number of flatfish species. Fisheries in the Celtic Sea are highly mixed, targeting a range of species with different gears.

Otter trawl fisheries took place for mixed gadoids (cod, haddock, and whiting), *Nephrops*, hake, anglerfishes, megrims as well as cephalopods (cuttlefish and squid). Most skates and rays were also taken by these fisheries. OTB and OTT Trawlers are dominant in the Celtic Sea with two major mesh size ranges 100-119 and 70-99mm codend (Figure 5.14). Within the DCR Level 6 métier OTB&OTT_DEF_70–99, there were two distinct métiers targeting mainly gadoids and benthic species (mainly anglerfish). The former declined in importance in recent years whereas the latter became more important. The fleet targeting *Nephrops* was OTB&OTT_CRU_70–99. Again there were two distinct métiers recognized by ICES WGCSE. One focused almost exclusively on large volumes of small *Nephrops* (i.e. where *Nephrops* accounts for >60% of the landed weight) and one with more mixed *Nephrops* and demersal fish catches. The former focused on the Celtic Sea deep whereas the latter is more spread out throughout the Celtic Sea where there is suitable habitat for *Nephrops*. Beam trawl fisheries (TBB_DEF_70–99) targeted flatfish (plaice, sole, and turbot), anglerfishes, megrim and cephalopods (cuttlefish and squid), while net fisheries targeted flatfish, hake, pollack, anglerfishes as well as some crustacean species. The fisheries were mainly conducted by French, Irish and English vessels. Some Belgian beam trawl fisheries targeted flatfish (in VIIe and VIIfg) while Spanish trawl and net fisheries targeted hake along the shelf edge (VIIhjk).

The mixed gadoid fishery predominately took place in ICES areas VIIf and VIIg with these areas responsible for >75% of the landings of each of cod, haddock and whiting. Catch Per Unit effort for these stocks was much higher than in the wider Celtic Sea (STECF, 2013), which may reflect higher abundance and/or increased targeting in these areas. Landings are predominately by French and Irish vessels, though UK vessels also take significant landings. Fishing effort for the main gears (otter trawlers, beam trawlers) has been relatively stable over the past ten years, though there has been an increase in otter trawl effort since 2009 (STECF, 2014), particularly for the large mesh trawlers (>100 mm). Unlike other parts of the Celtic Seas (VIa, VIIa) and the North Sea and eastern English channel (IV and VIId) the Celtic Sea is not subject to effort control measures under the long-term management plan for cod (excepting beam trawlers and gillnetters in VIIe as part of the Western Channel sole management plan), and so the increase in effort may be due to limiting effort regulation in other areas.

Figure 5.14 Summary of the main mixed fisheries interactions. Blue frames indicate which stocks were caught by the different fleets.

Rationale for selection of fleets and stocks

In the context of this project, the possibilities of candidate stocks were wide due to the diversity of fisheries in the Celtic Sea. The final choice of stock was to try 1) to move forward in regards to existing mixed fisheries modelling framework that have already tried to include some DLS stocks, 2) to consider a stock considered as vulnerable. On this basis, the natural candidates were the black and white anglerfish and *Nephrops* stocks. Those stocks have been already considered in previous mixed fisheries management modelling framework such as DAMARA and Fcube. Another candidate stock was the cuckoo ray as vulnerable species and also because skates and rays do not have any analytical assessment. Those stocks are geographically defined as covering VI, VII, VIIIabd for the cuckoo ray, VIIb-k, VIIIabd for both species of anglerfish, and FU16,17,19,20-21,22 in VII for *Nephrops*. It is worth noting that for both cuckoo ray and anglerfish, those stocks expands well beyond the Celtic Sea area and therefore any inclusion in a local mixed fisheries management framework requires some local split. This selection is also representative of the relative dominance of the main fleets/métiers operating in VIIbcefgh which were classified upon dominant gears and main demersal species targeted in the Celtic Sea.

Mixed fisheries issues

In common with the majority of EU demersal fisheries, those in the Celtic Sea can be characterised as being biologically and technically diverse with discarding of juvenile and over quota species problematic for many demersal species. In such fisheries, it is not entirely possible to control which species and how much of each is caught. In fact the economics will drive fishers to make best use of all TACs available to them. Recent years have seen contrasted recruitment for the gadoid stocks in the Celtic Seas and high levels of exploitation which has resulted in significant fluctuations in the stocks. Incompatibilities between the quota available has resulted in regulatory discarding as well as high-grading in the mixed fisheries, creating significant challenges in managing the exploitation of the stocks and leading to the introduction of a number of technical gear measures designed to reduce discarding of under size and over quota fish. Under the new management paradigm, management of TAC species which are currently discarded once the quota is exhausted will become increasingly important. This is also true for vulnerable species. Such 'choke' species could become the limiting factor for many fisheries and unless businesses adapt technically and tactically, failure to adequately deal with choke species will result in premature closure of fisheries with the situation that some quotas may be underutilised. To limit the uptake rate of choke species, businesses may respond through alternative harvesting strategies by adjusting spatial and temporal activity and/or uptake of species selective gears. There are a wide range of management instruments that could be used including technical measures, closed areas and seasons, preferential allocation of fishing opportunities, etc.

Stock assessments

At the start of the project, all the candidate stocks were assessed through surveys (Figure 5.15). The ICES advices were based on survey trends for anglerfish and cuckoo ray and therefore those stocks were classified as category 3. All *Nephrops* stocks in the Celtic Sea are considered as category 1 (data-rich) because of the use of underwater TV survey. Despite the relatively good data status of *Nephrops*, the lack of age-based analytical assessment providing biomass and fishing mortality estimates remains one of some issues to include them easily into mixed fisheries management models.

All considered stocks have existing time series of abundance indices (based on demersal trawl or underwater TV survey) and commercial catch. Therefore, the use of surplus production model (SPiCT) was possible for all stocks. The CMSY catch only model was also tested for *Nephrops* and cuckoo ray. It was not tested on monkfish as the catches are natively combined between species for these stocks and therefore the catch per species are estimates derived from total catches and observer at sea data. It was assumed that the survey indices were more reliable indicators of the abundance of each species and needed to be included into the assessment. Therefore, anglerfish was only assessed using SPiCT.

Stock	Assessment method at the start of the project	Assessments developed within DRuMFISH
Cod	Cat1 (age structured analytical)	
Haddock	Cat1 (age structured analytical)	
Whiting	Cat1 (age structured analytical)	
White anglerfish	Cat3 (survey index)	SPiCT
Black anglerfish	Cat3 (survey index)	SPiCT
Nephrops	Cat1 (UWTV index)	SPiCT, CMSY
Cuckoo ray	Cat3 (survey index)	SPiCT, CMSY

Figure 5.15 Summary of data-poor assessments available and developed within the DRuMFISH Celtic Sea case study.

Catch data were available for all stocks. Catch for both anglerfish species are generally aggregated as only Spain sort species in its catches therefore catch per species are estimates based on observer at sea data and do not actually represent the true catches for each species. For each stocks, the times series of catch are considered long enough to serve as input for any analytical assessment. Survey data were available for all stocks and were long enough to be considered in exploratory assessments.

Nephrops assessment was based on a series of underwater TV survey (UWTV). The survey indices serve as direct assessment which explains why these stocks are considered as category 1. However, the application of surplus production models to the *Nephrops* Functional Units is limited due to the availability and units of the time series. Catches (landings, and where available, discards) of *Nephrops* are expressed in terms of biomass (tonnes) whereas the survey in terms of numbers (millions). If there is a survey index value for a certain year, then the catch is usually also available in numbers. To apply a conventional surplus production model both time series must be of the same unit, i.e. they can only be applied for a time period restricted by the survey. The biomass UWTV survey index was approximated by multiplying the survey abundance by the annual mean weight in the catch.

Survey indices for elasmobranch species in the Celtic Sea are assessed through the Irish Groundfish Survey (IGFS) and French EVHOE-WIBTS both performed at quarter 4 each year. Within the ICES working groups, white anglerfish indices are derived from EVHOE-WIBTS, IGFS and Spanish SPPGFS survey also at quarter 4 but coverage and trends are considered by ICES not to be consistent. Black anglerfish abundance indices are only derived from the EVHOE-WIBTS survey. For a matter of consistency, only the EVHOE-WIBTS indices were used through this project.

Main results from the stock assessments

The assessments developed within DRuMFISH are described in detail below.

Cuckoo ray stock: A base run was conducted with all available input data and without constraining any parameters in SPiCT. In this configuration, the SPiCT model converged successfully. The biomass seems to fluctuate without an overall trend within the range of 30 000 – 40 000t but is estimated to be at around 2*B_{MSY}. Fishing mortality started at around 0.2, peaked in the late 1990s at around 0.3 and subsequently decreased to around 0.08 in 2015 and has been below F_{MSY} during the entire time series. However, the assessment is extremely uncertain. The estimated production curve is almost symmetrical but the data points cover only a small part of the production curve, indicating a lack of information and contrast needed for proper fit of the surplus production model. The one-step-ahead residuals for the catch and the three surveys used did not indicate any deviations from the model assumptions. Several unsuccessful attempts were made to reduce the uncertainty in the assessment. Setting the catches or indices to robust estimation hardly changed the model results. A full presentation of the ray assessment is given in Annex 6.

In conclusion, although this stock was selected as it is the least data-limited elasmobranch stock in the Celtic Sea region, nevertheless the data quality is poor. It was possible to fit a surplus production model to this stock but the assessment results are highly uncertain. The assessment lacks internal consistency and the stock status cannot be evaluated with certainty. Due to the shortcomings from this assessment it could be stated that currently it is not possible to model cuckoo ray or other ray / elasmobranchs stocks. Biomass estimates were highly sensitive to the use or not of survey indices.

***Nephrops* stocks:** In general, the default SPiCT runs with default parametrization performed poorly and the model seemed to struggle to reach a proper fit. This may be related to the short time series and missing contrast in the data. F appeared to be below F_{MSY} and biomass above B_{MSY}. However, confidence intervals were very high. Attempts to reduce them by changing model settings did not change anything. CMSY did not performed as this model requires good assumption on the depletion range and available data were not long enough to provide enough contrast in the data.

It can be concluded that is possible to fit surplus production models to the *Nephrops* functional units in the Celtic Sea but the results are uncertain and depend heavily on assumptions in the assessment models. The time series for *Nephrops* are very short and there is the issue of different units for the removals and the survey index. Furthermore, the time series lack information and contrast required for good model fits. Consequently, was difficult to model *Nephrops*, the assessments was highly uncertain and it was not possible to give estimates about absolute or relative stock characteristics such as stock size and fishing mortality based on surplus production models. It is therefore not yet advisable to include *Nephrops* on a functional unit base into simulation exercises. A possible intermediate solution is to use a "Robin Hood" approach assessing all *Nephrops* FUs together by using information from the less data-limited units for the more data-limited ones.

Anglerfish stocks: White anglerfish performed correctly in the Celtic Sea. However, B_{MSY} estimates (50kt) for the Celtic Sea appeared higher than the one estimated for the ICES stock area including both Bay of Biscay and Celtic Sea (40kt). Biomass appears to be above B_{MSY} and F below F_{MSY} but with strong uncertainty. Attempts to do the same approach for the black anglerfish did not provide any good model fit despite this species being more abundant in the Celtic Sea than in the Bay of Biscay. Thus, although SPiCT was usable for white anglerfish in the Celtic Sea it was unable to provide meaningful results for black anglerfish. The reason seemed to be related to assumptions in splitting the species in catches, or to the fact the survey indices were a good indicator of recruitment but not for biomass. For the white anglerfish, the fact biomass appears higher in the Celtic sea than for simulation covering the whole Celtic Sea and Bay of Biscay but with high uncertainties. The cause is probably related to the possibly misleading assumptions on the ratio of each species in the Celtic Sea catches. Therefore this assessment if included within an ICES advice should probably be considered as category 2 or 3. CMSY would not help solving both stocks as the problem seems to lies in the assumption on the catches. Survey estimates are also noisy or conflicting for black anglerfish.

Mixed fisheries modelling

ICES provide a Celtic Sea mixed fisheries advice on an annual basis for cod, haddock and whiting since 2014. All these stocks have a TAC set annually. The mixed fishery advice is based on Fcube derived from both the outputs of single-stock assessment and effort from the main fleets operating in the Celtic Sea. *Nephrops* stock units are divided into functional units but a single TAC is provided for the whole subarea 7. Management is currently not implemented in such a way that fishing opportunities in a given FU are in line with the resource in that FU. Cuckoo rays do not have specific TAC. Fishing opportunities are managed through an overall TAC by management unit, which includes all species of skates and rays. Both anglerfish species are managed through a combined TAC covering the Celtic Sea and Bay of Biscay.

Exploratory attempts have been done to include *Nephrops* into Fcube using the available UWTV survey data. One of the main problem was the single TAC for all FUs, considering two FUs in subarea 7 are outside the Celtic Sea. The split of TAC between FUs had to be considered as equivalent to the ratio of catches between FUs. The management strategy approach were done accordingly to those used by ICES for the Celtic Sea mixed fishery advice (7 scenarios: "min", "max", "cod", "haddock", "whiting", "status quo effort", "value").

Main results and conclusions

Overall, there were considerable technical interactions resulting in overshoots and undershoots of species catches relative to TACS in the Celtic Sea. Under the max scenario, where effort was driven by whiting, catches exceeded TACs for cod and haddock (Figure 5.16). A min scenario resulted in undershoots of all species. A cod scenario resulted in an overshoot of haddock, a considerable undershoot of whiting and an undershoot in *Nephrops*. While a haddock scenario resulted in considerable undershoots of whiting and *Nephrops*. Status quo and value scenarios resulted in an overshoot of all species except whiting. *Nephrops* did not appear limiting but effort may be driven above the single-stock advice for the gadoid species. No exploratory modelling approach was possible for cuckoo ray given the high level of uncertainty in the assessment. Fcube requires estimates of fishing mortality which was not possible to estimate in any assessment approach for this stock.

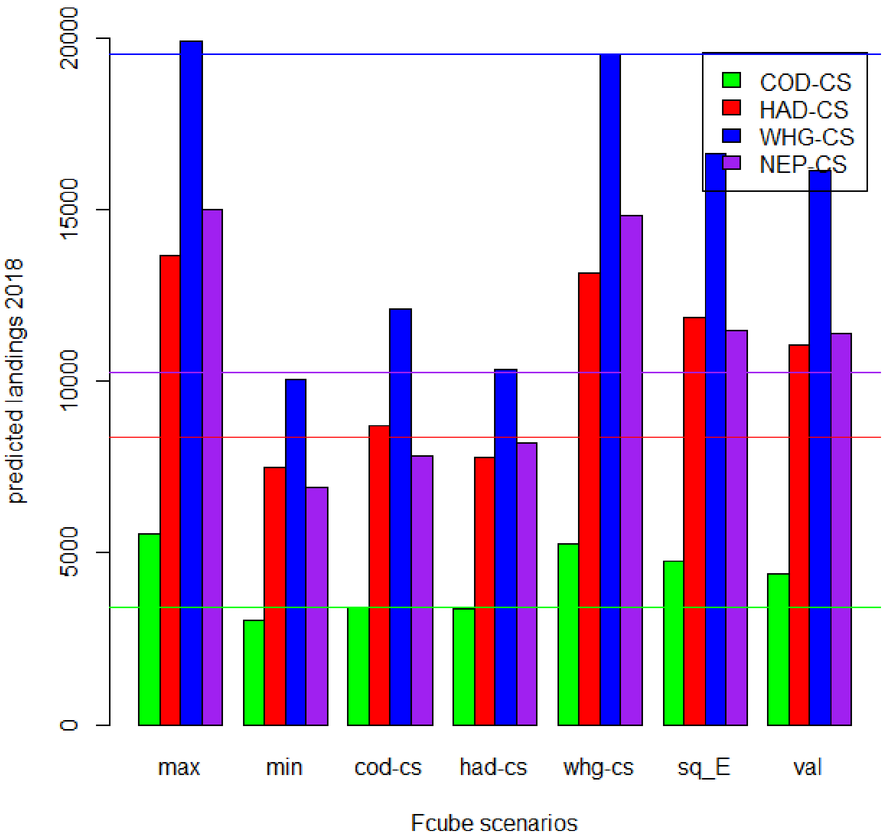

Figure 5.16 Celtic Sea mixed fisheries scenarios from Fcube, for the TAC year (2018). Nephrops stocks from ICES Areas 7. b – k are incorporated.

5.4. Bay of Biscay Case Study

Executive summary

Megrim and Sea Bass stocks were in ICES DLS category 3 and 5 respectively at the beginning of the project and now they have moved to category 1. Megrim is assessed using a Bayesian statistical catch at age analysis that allow different levels of data aggregation and missing data along years (Fernandez, Cerviño *et al.* 2010). Sea bass is assessed using the integrated SS3 assessment model (Methot and Wetzel 2013). The assessment models were accepted by ICES in specific benchmark workshops (ICES 2017). The advice of Megrim is given using category 1 HCR but due to deficiencies with the assessment the advice of Sea Bass was given using category 3 HCR in 2017. Both stocks are close to be exploited sustainably. The biomass is well above $B_{trigger}$ and the fishing mortality is close to F_{MSY}. *Nephrops* functional units 23 and 24 moved from category 5 to category 1 in the benchmark carried out in 2017.

Two different assessment models have been tested for white anglerfish, A4A (Jardim *et al.* 2014) and the SPiCT biomass production model (Pedersen and Berg 2017). The SPiCT fit was unstable and when its results were used in an MSE framework it failed to produce efficient management of the stock. The A4A model produced robust results but only goes until 2011 because length data was not available since. Its performance in the MSE framework was good. The trends obtained with both approaches, SPiCT and A4A, were similar. According to the SPiCT fit, the stock is exploited sustainably at present. According to the A4A fit the stock was exploited sustainably since 2009. The results of the work carried out in DRuMFISH was used to support the 2018 assessment benchmark. At this benchmark, the A4A assessment model for white anglerfish was accepted, and the stock is now in ICES category 1.

Red mullet was assessed using SPiCT model. The fit was quite robust and stable. However, the estimated biomass was low compared to the observed catches. According to the estimates of the model the stock is currently overexploited.

The performance of current management for monkfish (the HCR used by ICES for category 3 stocks) was better when it was tested under a mixed fisheries framework. This happened because under landing obligation the catch of monkfish was lower than the quota for some fleets.

The results obtained in the mixed-fisheries simulations were sensitive to the structure, the initial status and the dynamic of the stocks. Under current management the age-structured scenarios produced an overexploitation of monkfish. However, the economic performance of the fleet was better because monkfish was not limiting the fishery. On the contrary, under ICES HCR scenarios, the stock was exploited sustainably but its quotas limited the effort of the fleets and thus it produced a loss in the fishing opportunities of the other stocks. The results when biomass dynamic OM was used for Monkfish highlighted that the current management conciliate stable TAC, viable biological status for other stocks and economic performances for fleet. It does not enable however to use the maximum of fishing possibilities. Implementing an MSY approach for monkfish would tend however to increase monkfish fishing mortality and to increase incentive for highest quota behaviour which would endanger sole viability and thus economic viability in the long term.

In summary, if the stock is underexploited, while other stocks are fully or over exploited and landing obligation is not implemented, its exploitation at MSY can lead to lose on fishing opportunity and economic rent by over-exploiting the other stocks. On the contrary, if the stock is over-exploited and landings obligation is implemented, its exploitation at MSY can generate a loss in the economic rent by under-exploiting the other stocks.

In general, the quota uptake was better with multi-stock HCR. However, the quota uptake was lower than expected. The reason was that the relative exploitation of the stocks at global level was different than the relative exploitation at fleet level. If the relative exploitation of the stocks was similar at fleet and global level, the harmonization of single-stock TAC advice could be done at global level.

However, if the fleets that form the fishery are heterogeneous the harmonization of single-stock TAC quotas should be done at fleet level.

Context

This case study focuses on the Bay of Biscay stocks and fisheries (ICES Divisions 8abde). This area is characterized by a wide shelf extending west of France. The region includes part of French Exclusive Economic Zones (EEZs). Fisheries in the Bay of Biscay are managed under the Common Fisheries Policy (CFP). The fisheries advice of the stocks considered in this case study is provided by the International Council for the Exploration of the Sea (ICES), the European Commission's Scientific Technical and Economic Committee for Fisheries (STECF), and the South West Waters Advisory Council (SWWAC). The Bay of Biscay is a highly productive system where various types of mixed fisheries operate, catching more than 200 different species. Among those species, the 20 most important represent 80% of the total landings. The main exploited species in value are hake, megrim, monkfish, *Nephrops*, seabass and sole. The Bay of Biscay concentrates important mixed demersal French and Spanish fisheries of trawlers, netters and longliners with a high degree of technical interactions between them. Forty-five stocks are assessed by ICES, of which 7 have quantitative assessments and the rest are considered data-limited. Among the latter, 12 have survey indices and biological data available, while the remainder have only time-series of catch data.

Rationale for selection of fleets and stocks

The following stocks have been considered explicitly in the mixed fisheries management framework: The northern stock of hake in the Greater North Sea, Celtic Seas and northern Bay of Biscay; megrim west and southwest of Ireland, Bay of Biscay; sole in Bay of Biscay North and Central; white anglerfish in Southern Celtic Seas, Bay of Biscay; black-bellied anglerfish in Divisions West and Southwest of Ireland, Bay of Biscay; Northeast Atlantic mackerel in Northeast Atlantic; western horse mackerel in Northeast Atlantic; blue whiting in Northeast Atlantic; striped red mullet West of Scotland, Bay of Biscay, Southern Celtic Seas, Atlantic Iberian Waters; sea bass in Bay of Biscay North and Central; *Nephrops* in Bay of Biscay, FUs 23-24; pollack in the Bay of Biscay, Atlantic Iberian Waters; rays.

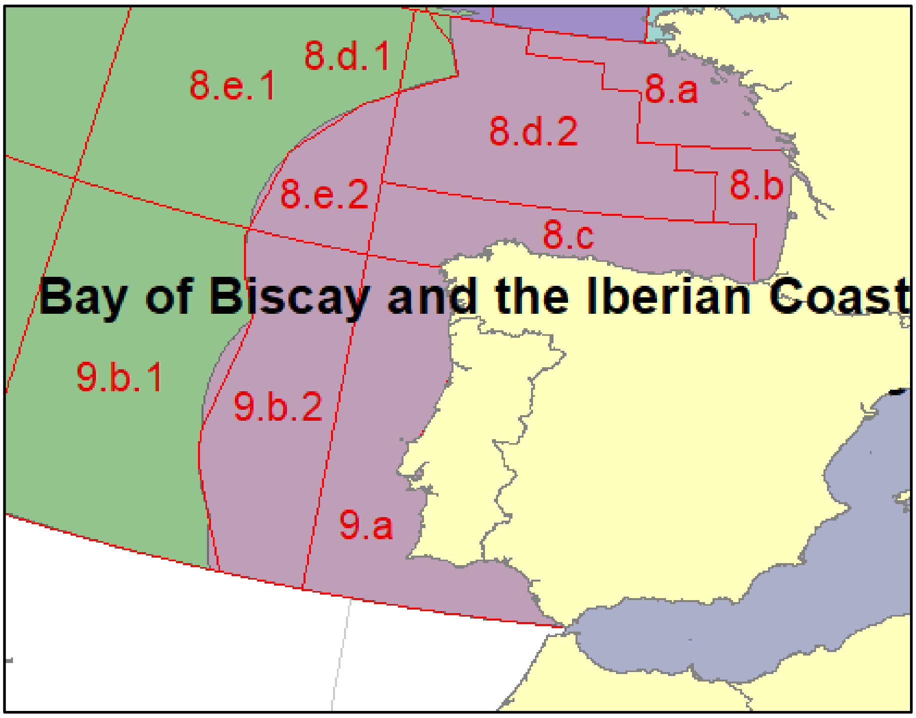

Figure 5.17 Overview of geographic areas included in theBay of Biscay case study. Adapted from www.ices.dk/marine-data/Documents/Maps/ICES-Ecoregions-hybrid-statistical-areas.png

Table 5.5 List of the fleets and stocks included in the modelling framework. Red rectangles indicate that the stock in that row is a target stock for the fleet in that column. In turn, orange rectangles indicate that the stocks are a secondary or bycatch stock for the fleet.

Fleets / Stocks	France							Spain					
										Trawlers			
	Gillnetters	Longliners	Mixed Coastal Bottom Trawlers	Mixed Bottom Trawlers	Nephtops Trawlers	Mixed Netters	Sole Netters	Longliners	Gillnetters	Pair Trawlers	Otter Demersal	Otter Cephalopods	Otter Pelagic
Hake													
Sole													
Megrim													
Anglerfish													
Monkfish													
Nephrops													
Sea Bass													
Pollack													
Horse Mackerel													
Cuttlefish													
Mackerel													
Blue Whiting													
Red Mullet													
Whiting													
Squids													
Skates													

The main fleets operating in the Bay of Biscay belong to France (FR) and Spain (SP). Their activity has been disaggregated at the métier level. The stocks included in the mixed fisheries simulations account for more than 80% of their catch. It is important to note that the spatial distribution of some of those stocks extends well outside the Bay of Biscay. Furthermore, there are some non-French and non-Spanish fleets also operating in the area. Hence, to account for the whole fishing activity related to the stocks considered and for the whole fishing mortality exerted on those stocks over their spatial distribution, some extra fleets have been added in the analysis. This includes several demersal fleets operating in area 7 (outside the area covered by CS) mainly catching hake, megrim, monkfish and an additional "miscellaneous fleet" accounting for the remaining fishing mortality.

The French fleets have been defined based on a selection of vessels operating in Divisions 8abd on demersal species. The classification of vessels into fleets is based on the combination of the dominant gear used and the main species targeted. These French fleets included in the analysis are (Table 5.5): Hake gillnetters; Sole netters; Mixed netters (monkfish sea bass, etc.); *Nephrops* trawlers (*Nephrops*); Mixed bottom trawlers (deep water: Hake, anglerfish, megrim and sole, cuttlefish, sea bass); Pelagic trawlers (Anchovy, sea bass, hake).

The Spanish vessels harvesting demersal stocks are aggregated in fleets characterized by dominant fishing gear, area, and target species. The Spanish fleets included in the analysis are: Pair bottom trawl targeting hake; Bottom otter trawl targeting demersal species. (Hake, megrims, and anglerfish); Bottom otter trawl targeting cephalopod and demersal species. (Squids, cuttlefish, and mullets are the main target species, secondary stocks, pout, seabass, hake…); Bottom otter trawl targeting demersal and pelagic species (Hake, mackerel and horse mackerel); Long liners targeting Hake; Gillnetters targeting Hake.

Mixed fisheries issues

The main potential mixed fisheries issues for the Bay of Biscay fisheries can be summarised as follows:

1. The potential mismatch of fishing opportunities between stocks (TAC overshoot or loss of fishing opportunity) is one of the main problems. Catch advices are made at stock level leading to inconsistencies in the consumption of quotas at fleet level. In some fleets the TAC share of some stocks is exhausted long before the share of others, leading to a high amount of over-quota discards. In a mixed-fisheries framework the landing obligation will prevent fleets to continue fishing when the quota of one stock, the limiting or choke stock, has been exhausted. Hence, fishing opportunities will be lost for the rest of the stocks.

2. Inefficient management of stocks. For several data-limited stocks, no stock assessments and/or reference points are available and TACs are based on recent levels of catch or landings. This could potentially lead to an inefficient use of resources. If the advice catch is above the maximum sustainable yield the stock would be overexploited and the opposite situation would produce a loss of fishing opportunities.
3. The gear selection patterns leading, for some stocks to the catch of small individuals and potential growth overfishing.
4. The impact on threatened species. Some of the skates and rays included caught by the fleets are 'near threatened' according to the IUCN red list (http://www.iucnredlist.org/).
5. The landing obligation could have an impact in the fishing operation. Due to the high number of species caught, it is likely that some of them will become limiting or choke species. Besides, fishers will have to keep all fish under TAC and Quota system on board leading to more species to be sorted and more biomasses to be taken to shore with no clear knowledge how this biomass will be processed. The result may be a loss of profitability of the fisheries in the short and mid-term. Solutions could come from an improvement in the selectivity and the avoidance of areas with large number of unwanted fish.
6. Species misidentification. For the anglerfish there is a problem of species identification in the catches between black-bellied anglerfish (*Lophius budegassa*) and anglerfish (*Lophius piscatorius*). Although biologically they are quite different, in appearance they are very similar. Some countries do not distinguish the catch of both species.

Stock assessments

Among the main demersal species of the Bay of Biscay, a large part of the stocks are data-limited and do not have an analytical stock assessment. In recent years ICES has conducted some work to develop stock assessments for some of the data-limited stocks. The DRuMFISH project supported the work of ICES and two of the stocks that were in category 3 and 5 at the beginning of the project are now in category 1. This is the case for megrim in divisions 7.b–k, 8.a–b, and 8.d, which is now analytically assessed using a Bayesian catch at age model. *Nephrops* functional units 23 and 24 are now assessed using TV surveys moved from category 5 to category 3. Furthermore, we have worked in the assessment of white anglerfish and striped red mullet. The assessment of white anglerfish was based on either the preliminary work carried out by ICES using the surplus production models SPiCT

Stock	Assessment method at the start of the project	Assessments developed within DRuMFISH
Megrim	Cat3 (survey index)	Cat1 (Age-based assessment)
Seabass	Cat5 (survey index)	
White anglerfish	Cat3 (survey index)	SPiCT, A4A
Striped red mullet	Cat5 (landings)	SPiCT
Black anglerfish	Cat3 (survey index)	
Nephrops	Cat1 (UWTV index)	
Pollack	Cat5 (landings)	
Whiting	Cat5 (landings)	
Skates and rays	Cat3 (survey index)	

Figure 5.18 Summary of data-poor assessments available and developed within the DRuMFISH Bay of Biscay case study.

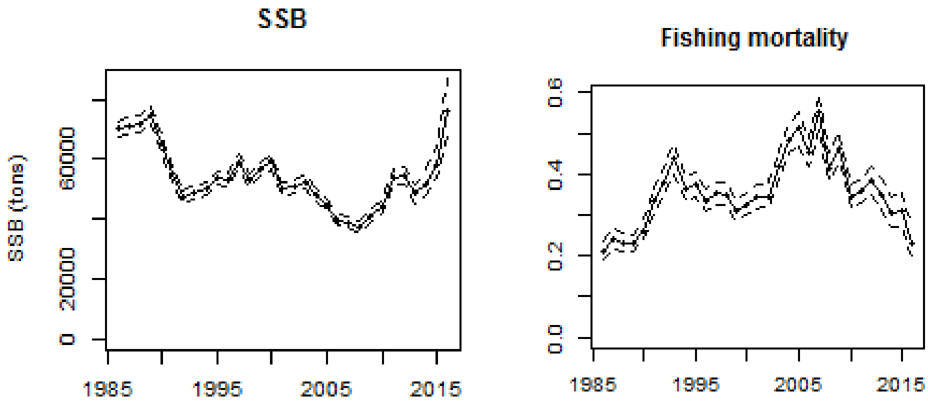

Figure 5.19 Time series of SSB (left panel) and fishing mortality (right panel) for Megrim in divisions 7.b–k, 8.a–b obtained using the Bayesian model. Dashed lines indicate 95% confidence bounds.

(ICES, 2015) or an assessment using FLa4a (Jardim *et al.* 2014). For striped red mullet, the assessment was carried out using SPiCT. Figure 5.18 summarizes the stock categories and the assessment methods. The assessments developed by DRuMFISH are presented in detail below.

Main results from the stock assessments

Megrim in divisions 7.b–k, 8.a–b: The megrim stock was classified as ICES category 3 at the beginning of the project and moved to category 1 after a benchmark working group carried out in 2016. The main problem with megrim was the poor quality of the discard data.

The stock is now assessed with a Bayesian statistical catch at age model (Fernandez *et al.* 2010) which allows the use of landing data with various levels of aggregation over time and incomplete discards data series.

The data used for the assessment of this stock are: (i) Catch at age time series by country, disaggregated by landings and discards. (ii) Scientific Surveys and commercial CPUEs, (iii) Biological data: maturity and weight at age and natural mortality independent of age and year.

According to the latest ICES stock assessment (ICES 2017), after a decreasing trend until 2006, the SSB has been increasing with a sharp increase to a maximum of the historical time series in the last years (Figure 5.19). The recruitments have fluctuated around 250 000 thousand of individuals in the whole series. The trend of the fishing mortality is the opposite of SSB's trend with a sharp decrease in F in recent years. In most part of the time series the SSB has been above $B_{trigger}$ and the fishing mortality above F_{MSY}. At present, the stock is close to be exploited sustainably.

White anglerfish in divisions 7b–k and 8abde: White anglerfish (*L. Piscatorius*) was in category 3. During the project two different stock assessment models have been tested, SPiCT (Pedersen and Berg 2017) and A4A (Jardim *et al.* 2014). The first model is a biomass production model which uses aggregated data to obtain estimates of biomass time series. The second model is a statistical catch at age model which uses catch at age data and abundance indices at age to estimate abundance at age over time.

SPiCT: During ICES WKProxy (ICES 2015) the EVHOE-WIBTS survey index and the LPUE of the Spanish trawler fleet from Vigo (VIGOTR7) were chosen as index of abundance and the LPUE from the UK trawler fleet (EW-FU06) was not included in the analysis. In the current study, all potential combinations of available catch, LPUE and survey indices were analysed. Based on an analysis of residuals, confidence intervals on B/B_{MSY} and F/F_{MSY} and retrospective analysis, it was found that the best model was the one including, as indices of abundance, the EVHOE-WIBTS survey and the EW-

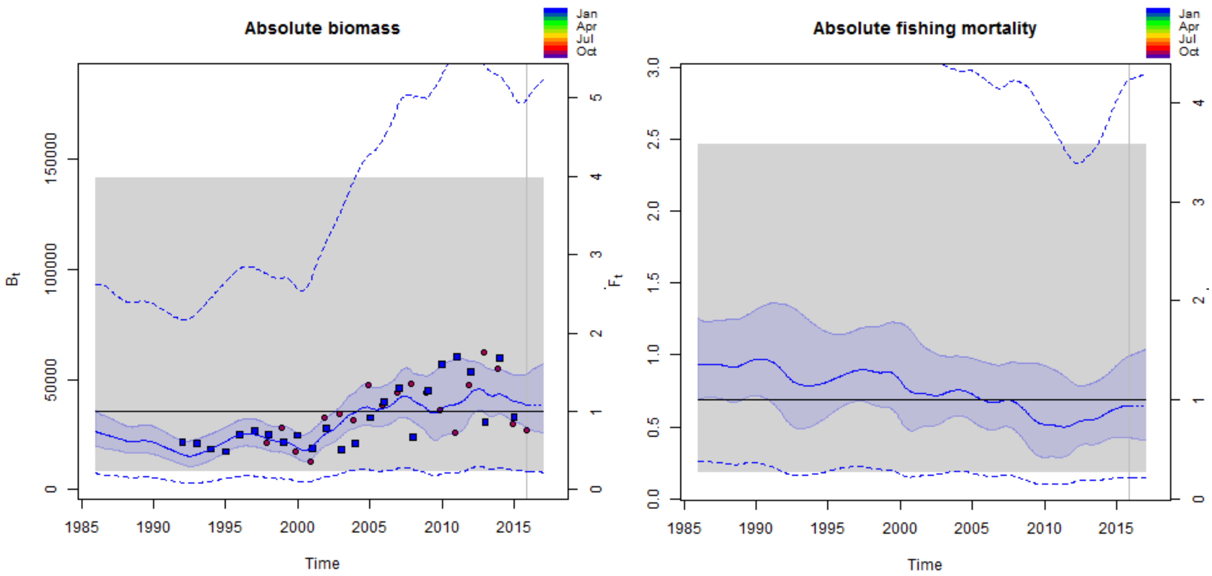

Figure 5.20 Biomass (left panel) and fishing mortality (right panel) time series of white anglerfish (L. piscatorious) obtained using SPiCT assessment model. Horizontal lines indiacte B_{MSY} (left panel) and F_{MSY} (right panel). Shaded areas indicate 95% confidence bounds.

FU06 LPUE data. The results did not improve using different time steps in the SPiCT settings and hence the default values were used as priors.

The data sets used for the SPiCT assessment of this stock were: (i) Wanted catch from 1986 to 2015. (ii) Spanish trawlers and English beam trawlers LPUEs. (iii) The French EVHOE-WIBTS survey, the Spanish Porcupine Groundfish Survey (SPPGFS-WIBTS) and the Irish Groundfish Survey (IGFS-WIBTS).

The uncertainty in the estimated biomass and fishing mortality time series was very high (Figure 5.20). In 2000 the biomass started increasing and after reaching B_{MSY} in 2005 it has been fluctuating slightly above it. The fishing mortality had a decreasing trend since the beginning of the series to 2010. Afterwards it started increasing and it is now close to F_{MSY} (Figure 5.20).

The fit was quite unstable. A retrospective analysis showed that the estimates were very sensitive to the incorporation of new information. Furthermore, using the estimated variance/covariance matrix to perform a bootstrap of the SPiCT fit the resulting uncertainty was that high that it was not possible to see any trend in the resulting population indicators. More details on the quality of the fit can be found in Annex 8.

A4A: One of the main uncertainties in relation to the biology and the assessment of white anglerfish is ageing and growth (Landa *et al.* 2008). Despite this difficulty, DRuMFISH attempted to fit the statistical catch at age assessment model a4a (Jardim *et al.* 2014), which allowed explicit consideration of uncertainty in growth and age.

The data sets used for the A4A assessment of this stock were: (i) Total landings from 1986 to 2011. (ii) Length frequency data from 1986 to 2011. (iii) The French EVHOE-WIBTS survey. (iv) Biological data: length-weight parameters, maturity ogive at length, Von Bertalanffy growth parameters.

The final results suggest that since the beginning of the 2000s the biomass has increased. The fishing mortality has fluctuated around 0.25 until 2008 when it started decreasing steadily until 0.15 (Figure 5.21). Since 2009 the stock is exploited sustainably.

Figure 5.21 Time series of Spawning Stock Biomass (left panel, in tonnes) and fishing mortality (right panel) obtained for white anglerfish using A4A. Shaded areas indicate 95% confidence bounds. Dashed horizontal lines lines indicate B_{MSY} (left panel) and F_{MSY} (right panel)

Striped red mullet in subareas 6 and 8, and in divisions 7.a–c, 7.e–k, and 9.a: Striped red mullet is assessed by ICES as a category 5 stock. Some length and age data are available but have not yet been used to produce catch at length and catch at age matrices. During DRuMFISH, a SPiCT stock assessment model has been fitted to the EVHOE-WIBTS survey index time series and to the catch time series available in ICES.

An initial fit used a long-time series of catch data and the EVHOE-WIBTS survey index but was found very dependent on the starting values of the parameters. Fits to a shorter time series (limited to the years where the EVHOE-WIBTS index is available) lead to results less sensitive to starting values and to better retrospective patterns. Results of this assessment must be taken with caution as the biomass estimates are very low and yearly catches are sustained by the annual growth of the stock.

The biomass level at the beginning of the time series was very low (Figure 5.22). In 2000 the biomass started increasing and reached the maximum in 2004. Afterwards it started decreasing again and at present it is in the historical minimum. The fishing mortality followed just the opposite trend. The stock has been overexploited in most of the time series. More details on the stock assessment and management of this stocks can be found in the Annex 8.

Mixed fisheries modelling

Fisheries in the Bay of Biscay are managed under the framework of the European Common Fishery Policy (CFP) and additional management measures introduced by the Member States. In 1983, the

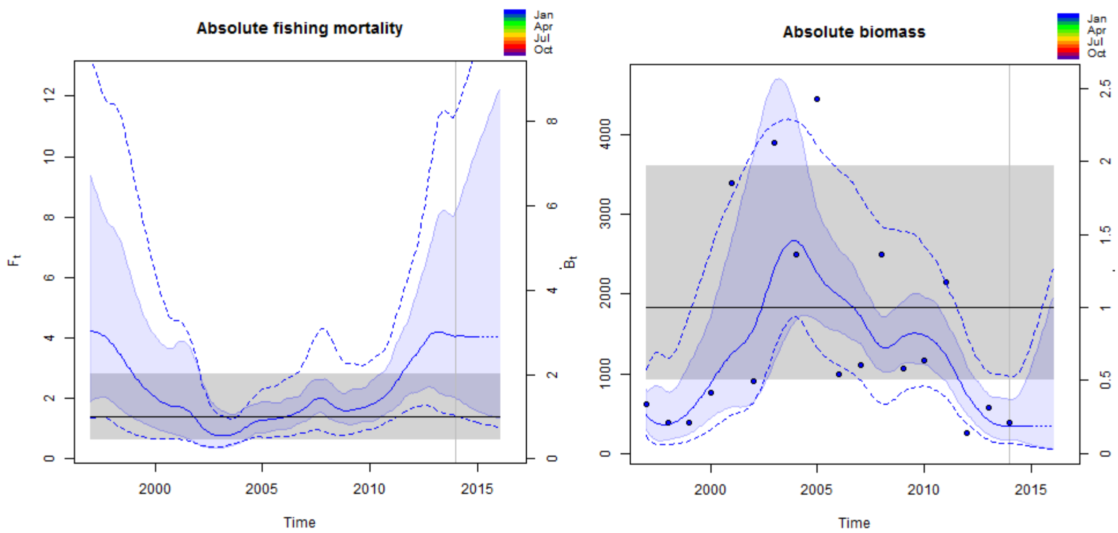

Figure 5.22 Biomass (left panel) and fishing mortality (right panel) time series of striped red mullet obtained using a SPiCT assessment model. Horizontal lines indicate F_{MSY} (left panel) and B_{MSY} (right panel). Shaded areas indicate 95% confidence bounds.

CFP introduced the concept of relative stability and established TACs as the main regulatory tool for EU fisheries management (Carpenter *et al.* 2016). Furthermore, additional technical measures have been introduced (minimum landing sizes, mesh sizes limits and selectivity measures), (EC Reg. No. 850/98 and 1239/98) along the years. In the last reform of the CFP in 2014 two of the main management tools introduced by the commission were the compromise with the maximum sustainable yield and the introduction of landing obligation (Salomon *et al.* 2014).

In France, management of quotas has been gradually transferred to Producer's Organizations (PO). French quotas are shared out into sub-quotas per Producer Organization (PO) based on a track-record criterion as defined by legal statutes dating from 2006 (JORF 2006). Allocation of sub-quotas by PO is based on the average landings of member producers over the period 2001-2003 (Larabi *et al.* 2013). Management of quotas within PO follows different rules decided within each PO. POs gradually imposed individual vessel quotas for common sole in response to increasing constraints on quota. Vessel quotas also apply for other species like European Hake or Mackerel in some PO. Seasonal quotas were also implemented in the *Nephrops* fishery for market reasons in some PO. Effort reallocation for the different fleets may be restricted by constraints in terms of TAC and national quotas consumption. Entry to the common sole fishery has been subject to permit holding since 2008 and licenses with numerus clausus were implemented for the *Nephrops* fishery and Sea Bass in 2004 and 2011, respectively

Additionally, the Spanish fleets are subject to total allowable effort (TAE) management, apart from some other technical measures (Iriondo *et al.* 2013). In Spain the TAE was introduced on top of the TAC regulation. In 1981 it was decided to list all the Spanish vessels operating in ICES Divisions 8abd and Sub-areas 6 and 7, to create the access rights to these fisheries (a single fishing right per vessel). The idea was to maintain these rights fixed even if the number of vessels decreased. When Spain joined the EU the number of vessels in that list was close to 300 and the so-called "300 list" was created. These fishing rights became transferable by area. A decrease in terms of number of vessels since the beginning of the 80s has made that the current TAE system is not constraining the operational days of the fleet any more. Concerning technical measures, some mesh size limitations and minimum landing sizes for some stocks have been implemented. Further information on how this fishery is managed can be found in (Prellezo *et al.* 2009; Prellezo 2010; Iriondo *et al.* 2013; Prellezo *et al.* 2016).

The bio-economic impact of the management of, or lack of, data-poor stocks was analysed in a MSE framework (Rademeyer *et al.* 2007; Punt *et al.* 2016). The Bay of Biscay demersal fisheries simulation frameworks developed within FLBEIA (Garcia *et al.* 2017) and IAM (Guillen *et al.* 2013) to assess the impact of the South-Western Multi-annual Management plan (STECF 2015) were used as a basis to develop the analyses carried out by DRuMFISH in the Bay of Biscay. At that time, among the main demersal species of the Bay of Biscay, a large part of the stocks were data-limited and in the simulation carried out for this impact assessment, only the stocks of hake, sole, mackerel, horse mackerel and blue whiting were modelled with full analytical population dynamic model. During the DRuMFISH project, the simulation frameworks were further developed to use new data-poor stock assessment results.

Fleet conditioning
In the case of French fleets, data of catch and effort by métier and species were derived from the SACROIS data base hosted by the IFREMER fisheries Information System and created under the National data collection Program to comply with the DCF. Economic data were parameterized based on the 2013 cost-structure (in percentage of the gross revenue) calculated by fleet from the sample of economic data by vessel collected under the DCF program and banked in the Secure Data Access Center (CASD).

In the case of Spanish fleets, the discard and landing data used was obtained from AZTI and IEO databases as part of the Data Collection Framework of the EU. It combined the information from log sheets, landing declarations, discards sampling trips and sales notes. The time series used went from the year 2009 to the year 2013. Costs of fishing of the fleets was obtained from the Annual Economic

Report of the EU fishing fleet (STECF 2014). To adapt these values to the specific conditioning of the case study, the cost average values were weighted by the proportion of vessels that each segment has, and then converted into weighted averages of the fleet. Three types of cost dynamics were considered in the study; variable costs and fuel costs change with the fishing effort, crew costs change with the revenue obtained from the landings and, finally, capital, depreciation and fixed costs change with the number of vessels. The average unit value of these costs (e.g. fuel cost per fishing day or fixed costs per vessel) was kept constant along all the years of the simulation.

Impact assessment scenarios
Various management strategies were tested, and their performance was evaluated against different population dynamics of white anglerfish. In each framework we analysed different issues related with the evaluation of management strategies. In FLBEIA we analysed the robustness of Harvest Control Rules to the biological uncertainty in white anglerfish. In IAM we analysed the value of information in impact assessments.

The robustness of Harvest Control Rules to biological uncertainty
The management strategies described below were tested to analyse the bio-economic performance of the fleets when the management of the stocks is moved from one category to a more data-rich one.

- Base case: This scenario mimicked the existing management advice as defined by the ICES DLS framework.
- White anglerfish MSY: As the base case but replacing the DLS category 3 harvest control rule for white anglerfish by the category 1 HCR.
- Multi-stock HCR: On top of the set of HCRs in the management scenarios defined above apply the multi-stock HCR, described in DRuMFISH project website (http://drumfish.org/WP3), to harmonize the single-stock TAC advices. This HCR was tested in two versions depending on the HCR used to produce the single-stock TAC of anglerfish.

To test the robustness of the management strategies to the inherent uncertainty in the dynamic of white anglerfish, the HCRs were tested against different OMs that differed in stock productivity and starting values (see Annex 8 for further details). The combination of the three HCRs with four different OMs resulted in 24 different scenarios.

The value of information
Several management and associated harvest control rules were assessed from a multi-criteria perspective with the objective to analyze the sensitivity of the results of the simulations to:

- The existing knowledge and, therefore, the population dynamics model (Operating Model) used for each stocks in the simulation framework. White anglerfish population dynamic in the operation model was included through either 1) a constant CPUE model or 2) a biomass dynamic model parameterized with a SPiCT stock assessment described in section 3 above.
- The harvest control rules chosen according to the knowledge on the stocks included in the modelling framework. Four harvest control rules were considered: constant effort corresponding to a status quo management, MSY based TACs for a selection of species (northern hake, sole and white anglerfish), ICES DLS 3 rule for white anglerfish only and constant TAC.

Furthermore, management strategies were tested under two alternative options, considering the potential fleets' behaviors regarding the landings obligation and discarding. Those options are based on the "min" and "max" scenarios developed under Fcube (Ulrich *et al.* 2011):

- Min- Lowest quota – landings obligation (Adjust effort by fleet-métier to quota by species for each fleet-métier cell where catches>0, then reconcile with the minimum of effort by fleet and métier)
- Max quotas and discards (Adjust effort by fleet-métier to quota by species for each fleet-métier cell where catches>0, then reconcile with the maximum of effort by fleet and métier accounting for discards for over-quotas catches)

All combination of management options, harvest control rules, operating model and landing obligation option min or max led to eight different scenarios.

Main results and conclusions

The performance of current management for monkfish (the HCR used by ICES for category 3 stocks) was better when it was tested under a mixed fisheries framework. This happened because under landing obligation the catch of monkfish was lower than the quota for some fleets.

The results obtained in the mixed-fisheries simulations were sensitive to the structure, the initial status and the dynamic of the stocks. Under current management the age-structured scenarios produced an overexploitation of monkfish. However, the economic performance of the fleet was better because monkfish was not limiting the fishery. On the contrary, under ICES HCR scenarios, the stock was exploited sustainably but its quotas limited the effort of the fleets and thus it produced a loss in the fishing opportunities of the other stocks. The results when biomass dynamic OM was used for Monkfish highlighted that the current management conciliate stable TAC, viable biological status for other stocks and economic performances for fleet. It does not enable however to use the maximum of fishing possibilities. Implementing an MSY approach for monkfish would tend however to increase monkfish fishing mortality and to increase incentive for highest quota behaviour which would endanger sole viability and thus economic viability in the long term.

In summary, if the stock is underexploited, while other stocks are fully or over exploited and landing obligation is not implemented, its exploitation at MSY can lead to lose on fishing opportunity and economic rent by over-exploiting the other stocks. On the contrary, if the stock is over-exploited and landings obligation is implemented, its exploitation at MSY can generate a loss in the economic rent by under-exploiting the other stocks.

In general, the quota uptake was better with multi-stock HCR. However, the quota uptake was lower than expected. The reason was that the relative exploitation of the stocks at global level was different than the relative exploitation at fleet level. If the relative exploitation of the stocks was similar at fleet and global level, the harmonization of single-stock TAC advice could be done at global level. However, if the fleets that form the fishery are heterogeneous the harmonization of single-stock TAC quotas should be done at fleet level.

5.5. Western Mediterranean demersal stocks case study

Executive summary

In this case study, the technical interactions among the demersal fishing fleets operating in GSA 6 were studies in a "competition analysis". In addition, results obtained from full analytical assessments for stocks targeted by demersal fleets in GSA06 were compared to results from data-poor methods. The methods that have been used are: MAGD (Multi-Annual Generalized Depletion model), LB-SPR (Length Based Spawning Potential Ratio), VIT (pseudo-cohort VPA) and CMSY. Finally, the mixed fisheries advice for management was approached with MEFISTO (Mediterranean Fisheries Simulation Tool; Lleonart *et al.* 2003).

The analysis of the competition among fishing fleets (or gears or métiers) suggested that OTB was dominant along the studied period 2006-2015, but its dominance decreased at the end of the studied period. This result suggests a decreasing specialization on the existing fishery resources; therefore, all fleets tended to fish the same resources. If the stock status of target species by fleet is known, the competition analysis may be used as a data-limited method to provide insights on the impact of fishing effort on mixed fisheries.

The MAGD model was applied to the hake bottom trawl fishery in the Catalan coast (northern GSA 6). The estimates of fishing mortality obtained are comparable to estimates produced by standard catch at age methods, although the model failed to reproduce accurately the magnitude of the recruitment peaks observed in the data set. The F estimated is consistently lower and with less variation than fishing mortality given in in STECF (2015). The MAGD model can be used for small-scale fisheries that are unlikely to meet the requirements of standard stock assessments using catch at age methods and can provide indicators (fishing mortality, vulnerable biomass) of interest to fisheries managers.

LB-SPR was applied to a hake fishery in the western Mediterranean (Murcia region, northern GSA 1, adjacent to GSA 6). The assessment indicated overexploitation levels of hake, comparable with those derived from conventional assessments for this species elsewhere in the Mediterranean Sea. According to our findings, the LB-SPR method can provide reliable stock assessments and allows calculating population trends in data-limited species, but requires a fine-grained understanding of the input data and their possible sources of bias. However, the assumptions underlying these data-limited methods (e.g. steady state) may lead to unequally biased annual estimates of both exploitation level and stock size.

We performed a data-limited stock assessment of *Merluccius merluccius* by incorporating available fishery-dependent data from 1982 to 2014 in GSA06 (NW Mediterranean). We used a pseudo-cohort VPA model (VIT) that, in general, showed good agreement with traditional assessments. Results suggest that fishing mortality increased since 1982. As a result, spawning stock biomass has decreased by two-thirds.

CMSY was tested using as input landings data and also, adding as input biomass index from bottom trawl surveys, option that may improve the performance of the model. Generally, the fishing mortality estimated was lower than that estimated from XSA. Nevertheless results are strongly dependent on the initial subjective expert's input on the initial and final status of the stock over the analysed period.

Forecasts of stock status recovery pathways for target species in the context of mixed fisheries were done for different management measures using MEFISTO. Management measures analysed here include changes in fishing effort and implementation of seasonal closures. The scenarios were chosen based on the objective of the current Spanish Mediterranean Fisheries Management Plan: i.e. a reduction of 20% of fishing effort. A total of nine scenarios were tested (i.e. accomplish 20% reduction of fishing effort after five years of implementation of the plan, applied to all fishing fleets, and 20% reduction applied only to bottom otter trawls; three months closures in winter or summer, during five consecutive years; 10%, 20% and 30% annual reduction of fishing effort applied to all fleets during five consecutive years; 20% reduction of fishing effort plus winter closure applied to OTB; 30% annual reduction during five consecutive years, applied to all fleets. This last scenario represents a reduction of 83% at the end of the five years and is the scenario that is closer to the target $F/F_{MSY} = 1$ in most of the species

Context

For the analysis of gear competition (Annex 11), all demersal species were included (49 in total). For the assessments and the MEFISTO forecasts, ten species were included: Hake (HKE, *Merluccius merluccius*), *Nephrops* (Nep, *Nephrops norvegicus*), red mullet (MUT, *Mullus barbatus*), striped red mullet (MUR, *Mullus surmuletus*), Deep-water rose shrimp (DPS, *Parapenaeus longirostris*), monkfish (MON, *Lophius piscatorius*), black-bellied anglerfish (ANK, *Lophius budegassa*), greater forkbeard (GFB, *Phycis blennoides*), four-spot megrim (LDB, *Lepidorhombus boscii*) and Blue and red shrimp (ARA, *Aristeus antennatus*). The stocks were assumed to be confined within the GSA boundaries (Figure 5.23).

"Fleet" is defined here as the combination of gear-fleet segment, following the DCF codes. A total of 10 fishing fleets were included in the case study: 4 OTB (fleet segments 6-12 m, 12-18 m, 18-24 m, 24-40 m); 2 LL (fleet segments 6-12 m, 12-18 m); 2 GNS+GRT (fleet segments 6-12 m, 12-18 m); 2 FPO (fleet segments 6-12 m, 12-18 m). Figure 5.24 gives an overview of the mixed fisheries interaction in the western Mediterranean case study. Depending on the analysis, not all fleets were considered. It is worth noting that species other than those selected are also targeted by the different fishing fleets. In the case of FPO, this is a very specialized gear targeting *Octopus vulgaris*; the species highlighted in Figure 5.24 represent a very small amount of the FPO catch.

Rationale for selection of fleets and stocks

The ten species were selected based on PSA (Productivity and Susceptibility Analysis). These species include the main fishing targets of the demersal fisheries in GSA 6 and those highly vulnerable. The selection of the fleets was based on their specific landings composition; all fleets targeting demersal resources were included.

Mixed fisheries issues

The main problem is the general decrease of catches in the last years and the competition among some of the fleets targeting the same species. OTB is the dominant fleet in terms of landings. In the Mediterranean fisheries are traditionally managed with input measures (effort limitations, technological restrictions). Discards of the commercial species is generally low, with some exception (e.g. blue whiting). Nevertheless, the impact of OTB on non-commercial species is high.

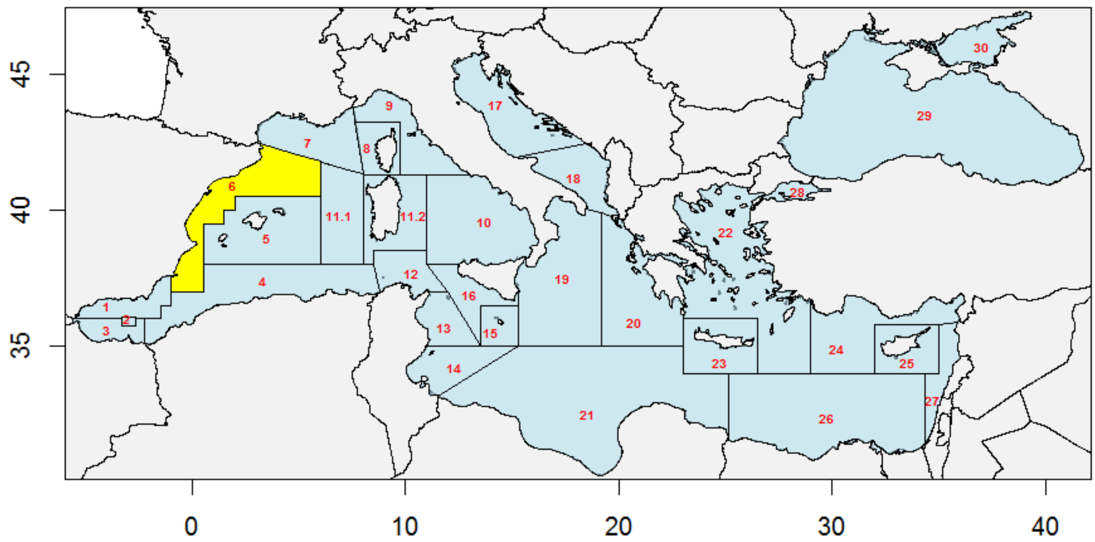

Figure 5.23 GFCM Geographical Sub-Areas (GSAs). In yellow, GSA 6, the study area of the Western Mediterranean case study.

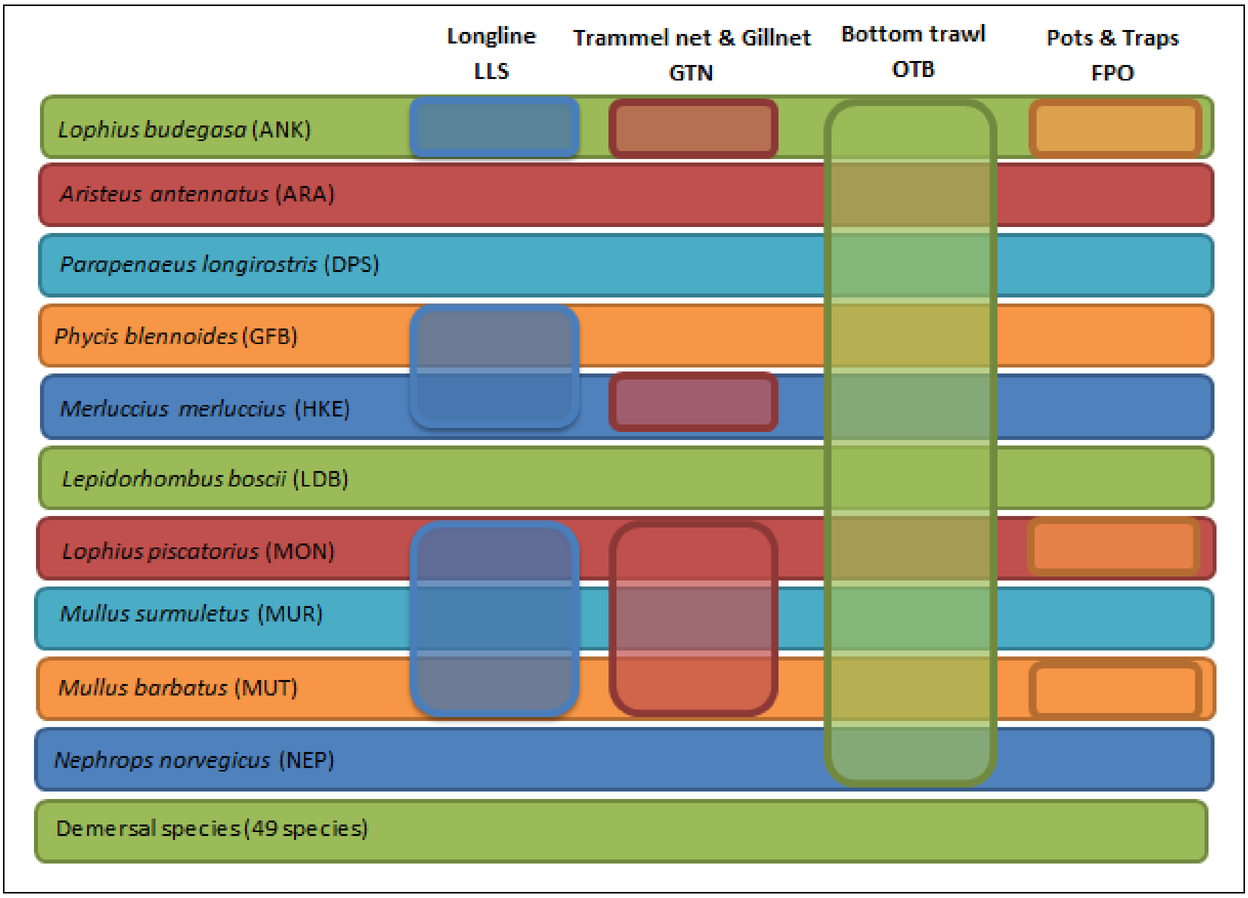

Figure 5.24 Representation of the mixed fisheries interaction in the western Mediterranean case study. Frames indicate which stocks were caught by the different fleets.

To study the mixed fisheries competition, a "competition analysis" was carried out. A full presentation of the analysis is given in Annex 11. In short, it provides two indices that that measure the competition among fishing fleets (or gears or métiers) in a multispecies fishery based on the species caught by each fleet. These indices can be used to measure the degree of dominance of each fleet and its level of independence from competition.

OTB was dominant along the studied period 2006-2015 and its dominance decreased at the end of the period, indicating that the landings of all fleets is less different now than it was at the beginning of the period. This result could be explained by decrease in the fishing resources; therefore, all fleets tended to fish the same resources. The largest trawlers (OTBVL2440) turned out to be more competitive than OTBVL1824 when competition is based on the CPUE that measures the competition gear- vessel. Small-scale fleets gained in independence by end, consequence of their specialization regarding their target species, although the dominance of the small-scale fishing is low. We recommend its use as a tool complementary to stock assessment.

Stock assessments

Figure 5.25 gives an overview of the assessment methods that were applied during DRuMFISH in the West Mediterranean case study. Data from well-assessed stocks assessed with standard VPA (XSA for demersal resources in GSA06) were used as benchmark, in order to identify the usefulness of several data-limited stock assessment methods to provide information on stock status, fishing mortality and stock size.

The data sources included the DCF, economic transversal data, the EC fleet register, fishing statistics by the Fisheries Department of the Autonomous Government of Catalonia, and data from different research projects.

The results obtained with several data-poor assessment methods for hake were compared with those obtained with age-based assessments (XSA). The first method was MAGD (see Annex 12), the second method was LB-SPR (see Annex 13), and the third method was VIT length pseudo-cohort analysis (see Annex 14). The results are summarised below. We conclude that these three methods can provide indicators on stock status and we recommend their use in data-poor situations. An overview is given in the next section.

In addition to the hake assessments that were run to contrast results of data-poor methods to results of data-rich methods, CMSY was applied to a large number of stocks, including red mullet, hake, monkfish, and four-spot megrim. The CMSY assessments were run on landings only, and on landings in combination with the MEDITS survey data. A detailed description of the methodology, data, and the outcomes of these CMSY assessments is presented in Annex 15. An overview is given in the next section.

Main results from the stock assessments

For hake, several methods (MAGD, LB-SPR, VIT length pseudo-cohort analysis) were tested and contrasts to existing data-rich assessment methods used for the stock. The results are summarized below:

<u>MAGD Multi-Annual Generalized Depletion model.</u> This method was applied to hake in bottom trawl fisheries. The fishing mortality estimated here (0.97 to 1.32 yr^{-1}) is consistently lower and with less variation than the fishing mortality given in STECF (2015), which varies between 1.26 and 2.0 yr^{-1}. This difference can be explained by the fact that F in the MAGD model is not calculated directly, but derived from the catchability to effort relationship.

Stock	Assessment method at the start of the project	Assessments developed within DRuMFISH
Lophius budegasa	Cat1 (XSA)	CMSY
Aristeus antennatus	Cat1 (XSA)	CMSY
Parapenaeus longirostris	Cat1 (XSA)	CMSY
Phycis blennoides	Cat1 (XSA-GSA9)	VIT, CMSY
Merluccius merluccius	Cat1 (XSA)	VIT, CMSY,MAGD, LBSPR
Lepidorhombus boscii	-	VIT, CMSY
Lophius piscatorius	-	VIT, CMSY
Mullus surmuletus	Cat1 (XSA-GSA9)	VIT, CMSY
Mullus barbatus	Cat1 (XSA)	VIT, CMSY
Nephrops norvegicus	Cat1 (XSA)	VIT, CMSY

Figure 5.25 Overview of the assessment categories and assessment methods developed during DRuMFISH in the Western Mediterranean case study.

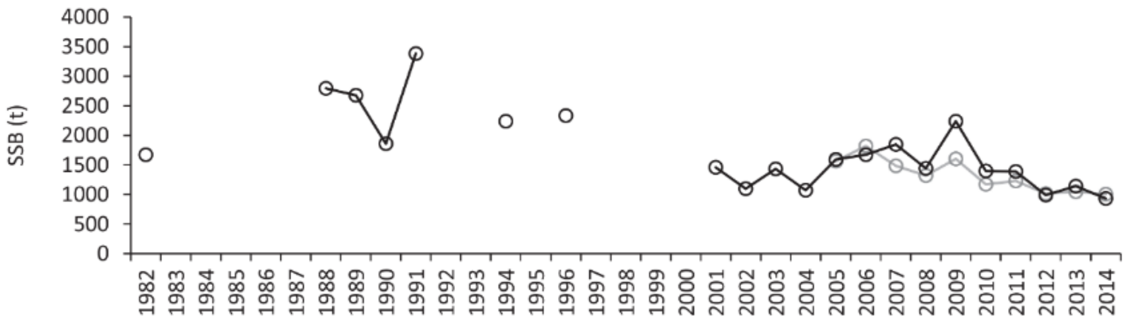

Figure 5.26 VIT (black line) and XSA (gray line) estimates of Spawning stock biomass of hake derived from the trawler fleet catches in Northwest Mediterranean Sea (GSA06).

LB-SPR was applied to hake, a species with well-known biology. SPR estimates under four life-history scenarios were sensitive to the quality (sample size) of the length frequencies. Consequently, more accurate SPR estimates were found for annual samples larger than 2000 individuals. The assessment indicated overexploitation levels of hake (F/M> 2, SPR< 10%) comparable with those derived from conventional assessments for this species elsewhere in the Mediterranean Sea. However, estimation of SPR for a species as hake meeting strong harvesting on juveniles and older individuals are partially inaccessible for fisheries will lead overestimation of fishing mortality and underestimation of SPR. The performance of this method in the Mediterranean context was recently explored at STECF-17-12 (STECF 2017a).

VIT The analysis was performed on the north-western Mediterranean stock of hake. The pseudo-cohort VPA approach offered stock indicator trends with a remarkable agreement regarding conventional VPA outputs, and spawning stock biomass being in the lower ranges in recent years (Figure 5.26). However, annual estimates of fishing mortality for less caught ages were noticeably different between conventional and pseudo-cohort VPA, promoting bias in stock size estimates. The pseudo-cohort VPA looks an appropriate tool for exploring the historical trends of the stock indicators from sparse data. Nevertheless, the performance of this data-limited method (i) under different deviation levels of equilibrium assumption, (ii) including species that exhibit contrasting stock status and (iii) involving all possible life history traits, should be further addressed. This is particularly relevant as mixed fisheries usually involve species holding a wide range of life and exploitation histories.

CMSY Generally, the estimated Fs were lower than those estimated with other methods. Results improved when using survey data. An overview of F/F_{MSY} and B/B_{MSY} for all 10 stocks is given in Table 5.6. It should be noted that the results for all stocks are very sensitive to the assumed priors that are used in the models. Also, there were differences observed between the assessments that included or excluded the MEDITS survey data. For hake, the results suggest that $F>F_{MSY}$ for most of the study period and $B<0.5B_{MSY}$ (Figure 5.27).

Table 5.6 F/F_{MSY} and B/B_{MSY} estimates from CMSY for the 10 demersal stocks in the Western Mediterranean case study.

Stock	F/F_{MSY}		B/B_{MSY}	
	MEDITS	Catch	MEDITS	Catch
Black-bellied anglerfish (ANK)	1.49	0.85	0.67	1.06
Blue and red shrimp (ARA)	1.36	1.18	0.86	0.89
Deep-water rose shrimp (DPS)	1.41	1.59	1.23	1.13
Greater forkbeard (GFB)	3.31	1.64	0.46	0.65
Hake (HKE)	1.19	0.95	0.43	0.47
Four-spot megrim (LDB)	3.66	1.85	0.48	0.82
Monkfish (MON)	0.40	0.40	1.03	1.02
Striped red mullet (MUR)	1.40	1.68	0.33	0.30
Red mullet (MUT)	1.65	1.63	0.66	0.63
Nephrops (NEP)	1.11	1.28	0.78	0.68

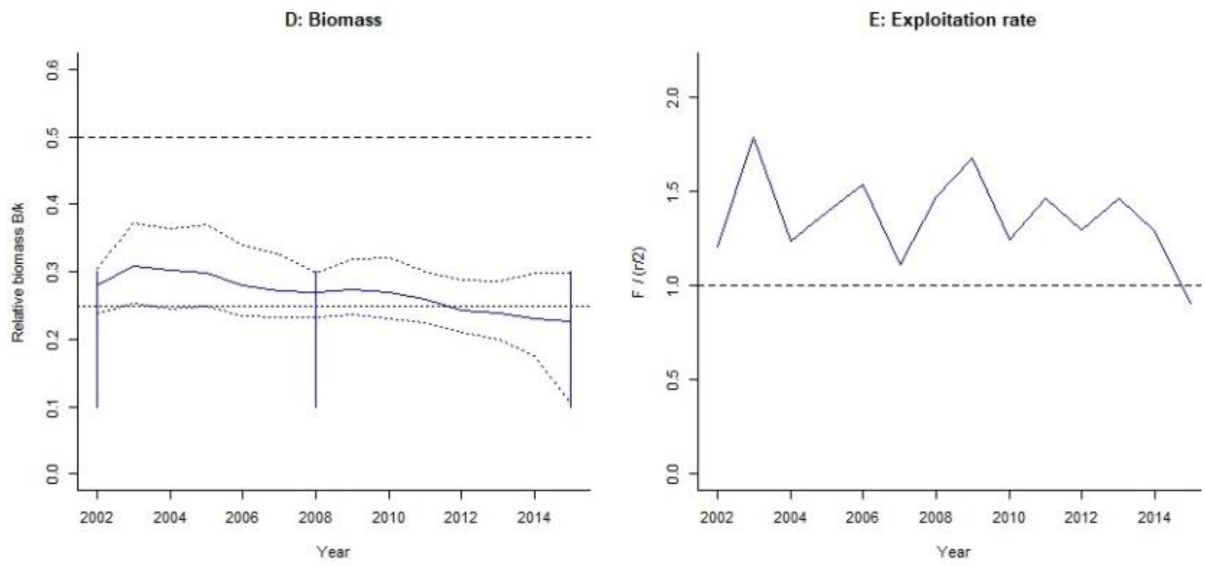

Figure 5.27 Summary of assessment results for hake in GSA06 when using landings as input data. Stock biomass (left panel) relative to carrying capacity (left panel) and exploitation rate relative to F_{MSY}. Horizontal dashed lines indicate B_{MSY} (left panel) and F_{MSY} (right panel). Horizontal dotted line in the left panel indicates 0.5 B_{MSY}.

Mixed fisheries modelling

The system is managed by effort limitation (seasonal and spatial closures; bottom trawl forbidden > 50 m depth) and minimum landings size established at Community level (EC Regulation 1967/2006), national level (Spain) and Autonomous Governments. These last two include species not considered in the EC Mediterranean Regulation. To date, no TAC is implemented in demersal fisheries in the Mediterranean. There is no specific management target for the data-limited species. Locally, an additional fishing effort limitation is applied in certain areas (e.g. in some *Aristeus antennatus* fishing grounds and spatial closure in hake recruitment fishing grounds in the northern GSA 6).

MEFISTO was used for the mixed fisheries modelling. In the context of the DRuMFISH project, the biological sub-model was used to test management measures that result in a sustainable mixed fishery. In MEFISTO, technical interactions are explicitly accounted for. Each management measure affects the target species differently, depending on particular life-history traits (e.g. timing of recruitment). It produces F and F/F_{MSY} for each simulation scenario.

A full presentation of the methods and results is given in Annex 10. MEFISTO has been jointly applied to the ten selected species. Most of these species are fished exclusively by bottom trawl. Fleets corresponded to the combination of gear and fleet segment. A total of seven fleets were considered, 3 OTB, 2 longline and 2 GTS (gillnet and trammel net). Economic data were used for the allocation of landings by species among fleet segments. This allowed setting partial Fs by species and fleet.

The choice of the scenarios was based on the main objective of the current Spanish Mediterranean Fisheries Management Plan for 2013-2017 i.e. a reduction on 20% of fishing effort at the end of the plan as well as alternative scenarios A total of nine scenarios were tested (i.e. reach 20% reduction of fishing effort after five years of implementation of the plan, applied to all fishing fleets, and 20% reduction applied only to OTB; three months closures in winter or summer, during five consecutive years; 10%, 20% and 30% annual reduction of fishing effort applied to all fleets during five consecutive years; 20% reduction of fishing effort plus winter closure applied to OTB; 30% annual reduction during five consecutive years, applied to all fleets. This last scenario represents an effort reduction of 83% at the end of the five years and it is the scenario that would be closer to the target F/F_{MSY} = 1 in most of the ten analysed species.

Main results and conclusions

From these simulations it can be concluded that the proposed effort reduction of 20% of fishing effort at the end of five years would not lead to the target $F/F_{MSY} = 1$, which would require a reduction of more than 80% of the fishing effort. This reduction would imply that one vessel would be allowed fishing one month a year, or even less in the case of some small-scale fleets.

According to the values of F_{bar} from MEFISTO initialization and F_{MSY} from standard stock assessments, the situation at the start of the simulation is that some of the main fishing targets are highly over exploited, in particular *Mullus barbatus*, *Parapenaeus longirostris* and *Lophius budegassa* ($F/F_{MSY} \geq 6$). For hake, F/F_{MSY} was 5.86. In the case of the other two crustaceans, *Aristeus antennatus* and *Nephrops norvegicus*, F/F_{MSY} was 2.17 and 3.81 respectively. For the remaining four selected species, *Phycis blennoides*, *Lepidorhombus boscii*, *Lophius piscatorius* and *Mullus surmuletus,* $F/_{FMSY}$ was <1. It is worth noting that these values are comparable those given in different EWGs, as for example, *Lophius budegassa*, $F/F_{MSY} = 6.5$, STECF 15-06; *Parapenaeus longirostris*, $F/F_{MSY} = 5.21$, STEC 13-22; *Merluccius merluccius,* $F/F_{MSY} = 5.35$, STECF 15-18; *Aristeus antennatus,* $F/F_{MSY} = 2.08$, STECF 15-18. We recommend its use as a tool complementary to stock assessment.

5.6. Adriatic Sea case study

Executive summary

The *rapido* is a modified beam trawl used mainly in the Adriatic Sea for fishing scallops and other molluscs in sandy offshore areas (in the North-East Adriatic) as well as flatfish in muddy inshore areas (mainly central Adriatic) (Pranovi *et al.* 2000, 2001, 2004). This gear is a beam trawl composed by an anterior rigid metallic frame, a wooden table acting as depressor and maintaining the mouth in close contact with the sea bottom, and a series of iron teeth that penetrate in the superficial sediment.

Although recent studies have been implemented to evaluate the impact of this gear on sole and mantis shrimp, in particular in the Central Adriatic area, no information on the stock status is available on the main target and accessories species of this fishery in the northernmost area of Adriatic Sea especially due to the lack of data and biological information. In the present case study, the analyses of such data-limited stocks (DLS) have been carried out to estimate exploitation state. Those were never presented before both in FAO-GFCM or STECF. In particular, the analyses have been performed on the following stocks: *Pecten jacobaeus*, *Aequipecten opercularis*, *Sepia officinalis*, *Scophthalmus rhombus*, *Bolinus brandaris* and *Penaeus kerathurus*. In addition, two species (namely *Solea solea* and *Squilla mantis*) that are assessed using age-based approaches in FAO-GFCM and STECF, were assessed to validate the accuracy and precision of the DLS model. The entire suite of species allowed to perform a complete mixed-fisheries analysis.

The model employed to analyse the stocks mentioned before was CMSY (Froese *et al.* 2016). CMSY is a Monte-Carlo method that estimates fisheries reference points (MSY, F_{MSY}, B_{MSY}) as well as relative stock size (B/B_{MSY}) and exploitation (F/F_{MSY}) from catch data and broad priors for resilience or productivity (r) and for stock status (B/k) at the beginning and the end of the time series. Part of the CMSY package is an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM). The main advantage of BSM compared to other implementations of surplus production models is the focus on informative priors and the acceptance of short and incomplete (= fragmented) abundance data. *P. jacobaeus* and *S. rhombus* showed a bad status, with biomass below 50% of B_{MSY} and F much higher than F_{MSY}. *S. officinalis*, *A. opercularis* and *B. brandaris* showed a better state with biomass close to B_{MSY} and F below F_{MSY}. *S. solea* showed a similar status with biomass and fishing mortality slightly above the respective reference points. The healthiest species results to be the *P. kerathurus* and *S. mantis*, for whom biomass is above the B_{MSY} and the F is below F_{MSY}.

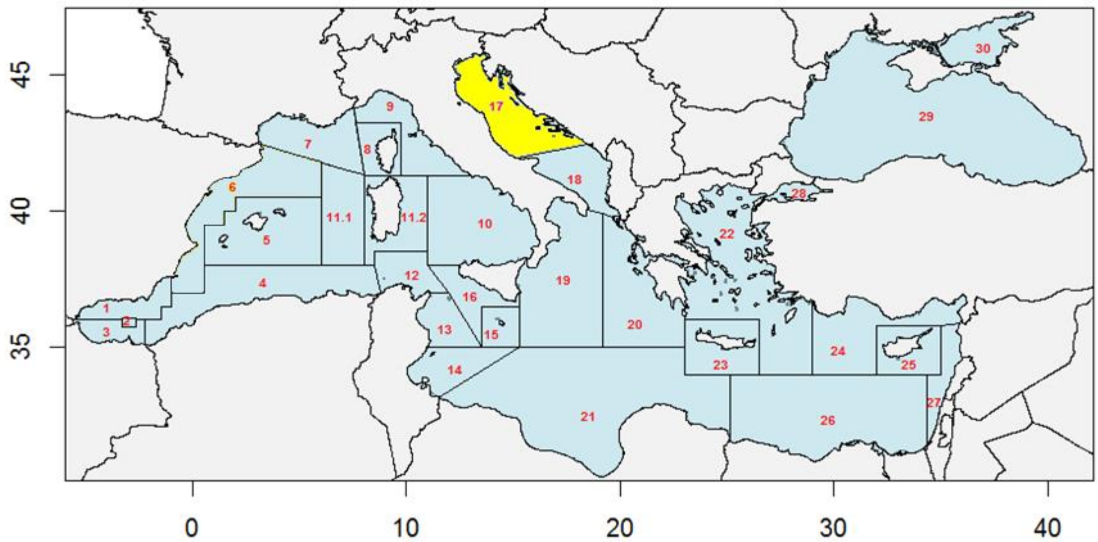

Figure 5.28 GFCM Geographical Sub-Areas (GSAs). In yellow, GSA 17, the study area of the Adriatic case study.

A multivariate analysis was done using the analysed stocks as variables and the gears landing them as samples. The analysis clearly grouped the *rapido* trawl fishery together. Therefore, the multi-fleet analysis focused on this activity. Simulations of different HCRs have been carried out, using the multi-stock CMSY forecast. The results suggested a recovery of most of the stocks by 2030 fishing at 0.5 F_{MSY}. However, when taking into account the mixed-fisheries nature of the fishery, results suggested a low probability that all the stocks are going to recover in the medium term because *P. jacobaeus* and *S. rhombus* show a low status. Therefore, other management measures (e.g. spatial and seasonal closures) are needed together with a fishing effort reduction to allow a recovery of the two stocks.

Context

The stocks included in the case study are listed in Table 5.7. The stocks were considered to be confined in the central and northern sector of the Adriatic Sea (FAO-GFCM Geographical Sub-Area 17), where the *rapido* trawl fishery is operating. This conclusion has been demonstrated for *S. solea* using genetic markers by Sabatini *et al.* (2018). The other stocks are characterized by a low rate of mobility (e.g. *P. jacobae*us), therefore such assumption seems reasonable.

Rationale for selection of fleets and stocks

Some of the stocks considered in the present case are important demersal target species for several fleets using both passive and active gears and are shared between Italy, Slovenia and Croatia. However, the main fleet exploiting the whole assemblage considered is the *rapido* trawl fleet, mainly utilised in Italy. This gear is a beam trawl composed by an anterior rigid metallic frame, a wooden table acting as depressor and maintaining the mouth in close contact with the sea bottom, and a series of iron teeth that penetrate in the superficial sediment. This fishery is characterized by a high ratio of discarded to landed fraction, that is around 6:1 for the Italian *rapido* targeting sole and 1:1 for the Italian *rapido* targeting scallops (Pranovi *et al.* 2001).

Mixed fisheries issues

Although recently the impact of this gear on common sole and mantis shrimp has been evaluated, no information on the stock status is available on the main target and accessories species of this fishery in the northernmost area of Adriatic Sea, such as molluscs (in particular *Aequipecten opercularis, Pecten jacobaeus, Bolinus brandaris, Sepia officinalis*), crustaceans as *Penaeus kerathurus* and other flatfish as *Scophthalmus rhombus*. The main reason of such lack of information in term of status of exploitation is also due to the fact that such species can be considered as data-limited stocks, being available only landings and in abundance indices from trawl survey. Moreover, some of the stocks are showing a depleted status and the impact of *rapido* trawl fishery needs to be carefully evaluated for this potential threatened species.

Stock assessments

The model employed in the project was CMSY (Froese *et al.* 2017). In particular, the analyses have been performed on the following stocks: *Pecten jacobaeus*, *Aequipecten opercularis*, *Sepia officinalis*, *Scophthalmus rhombus*, *Bolinus brandaris* and *Penaeus kerathurus*. In addition, the main target

Table 5.7 List of stocks analysed in the Adriatic Sea case study

Species	Common English name
Pecten jacobaeus	Great Mediterranean scallop
*Solea solea**	Sole
Sepia officinalis	Common cuttlefish
Aequipecten opercularis	Queen scallop
Scophthalmus rhombus	Brill
Bolinus brandaris	Purple dye murex / Murex
Penaeus kerathurus	Caramote prawn
*Squilla mantis**	Mantis shrimp

* Stocks also evaluated with analytical models in FAO-GFCM and STECF.

	Assessment method at the start of the project	Assessments developed within DRuMFISH
Solea solea	Cat1 (SS3 model)	CMSY
Squilla mantis	Cat1 (XSA)	CMSY
Pecten jacobaeus	-	CMSY
Aequipecten opercularis	-	CMSY
Penaeus kerathurus	-	CMSY
Sepia officinalis	-	CMSY
Scophthalmus rhombus	-	CMSY
Bolinus brandaris	-	CMSY

Figure 5.29 Assessment methodologies used to evaluate the stocks considered in the Adriatic case study.

species of this fishery (namely *Solea solea*) and one of the most important accessory species (*Squilla mantis*), which are assessed using age-based approaches both in FAO-GFCM and STECF, have been evaluated to validate the accuracy and precision of the model used for the analyses of data-limited stocks and to perform a more complete multi-species mixed fisheries analysis (Figure 5.31 Percentage of stocks that will reach BMSY in the projection of stock biomasses up to 2030 according to the following scenarios: continuous line corresponding to an exploitation of F equal to 0.5 F_{MSY} for all stocks; dotted line corresponding to an exploitation of F equal to 0.6 F_{MSY} for all stocks; broken line corresponding to an exploitation of F equal to 0.8 F_{MSY} for all stocks; dashed line scenario corresponding to an exploitation of F equal to 0.95 F_{MSY} for all stocks. The different colours represent the percentage of stock that will reach B_{MSY} in 2030.Figure 5.29).

The use of such model is justified by the availability of long time series of landings and abundance indices for the stocks considered. The source of landings from 1972 to 2015 for Croatia and Slovenia was FAO-FISHSTATJ database, while ISTAT-IREPA datasets have been used for Italy. Such sources have been combined in the most recent period with official EC data available from the data collection framework. Discards of the considered stock can be assumed negligible or very low (STECF EWG 15-02) and in some cases (e.g. *P. jacobaeus* and *B. brandaris*) a high rate of survivability can be expected.

CMSY was first run using a basic setting similar to all the species. Then, the model was refined testing different settings for each species with the aim of finding the best results in order to pursue the multispecies analysis. In order to define the priors a literature review has been carried out.

P. jacobaeus and *S. rhombus* showed a bad status, with biomass below 50% of B_{MSY} and F much higher than F_{MSY}. *S. officinalis*, *A. opercularis* and *B. brandaris* showed a better state with biomass close to B_{MSY} and F below F_{MSY}. *S. solea* showed a similar status with biomass and fishing mortality slightly above the respective reference points. The healthiest species results to be the *P. kerathurus* and *S. mantis*, for whom biomass is above the B_{MSY} and fishing mortality is below F_{MSY} (Figure 5.30). A presentation of all assessment output is given in Annex 16.

Kobe plots in Figure 5.30 show wide ranges of uncertainties in the last year of assessment. Although this could represent a limitation of the model, the advice derived from CMSY could be straightforward if is based on the last decade of data. Moreover, the diagnostics of the model (see second interim report for more details) show a good fitting in most of the case indicating that the approach would be useful for managers.

One assumption of CMSY is that the calculated *r* and *k* estimates are specific of a stock and do not refer to the species in general. This means that species interactions and environmental impact are implicitly considered in these estimates, because the intrinsic rate of population increase and the carrying capacity are measured with respect to a certain marine area. The *r* and *k* parameters estimated by CMSY summarised these life-history traits in that area, given the species' interactions in that specific environment. Thus, the CMSY estimates indirectly involve natural mortality caused by predation and somatic growth depending on available food resources, and recruitment conditioned by environmental conditions and by parental egg production (Froese *et al.* 2016). This assumption implies that interactions between different stocks are implicitly taken into account by CMSY, when employed in a multi-species model on a certain area.

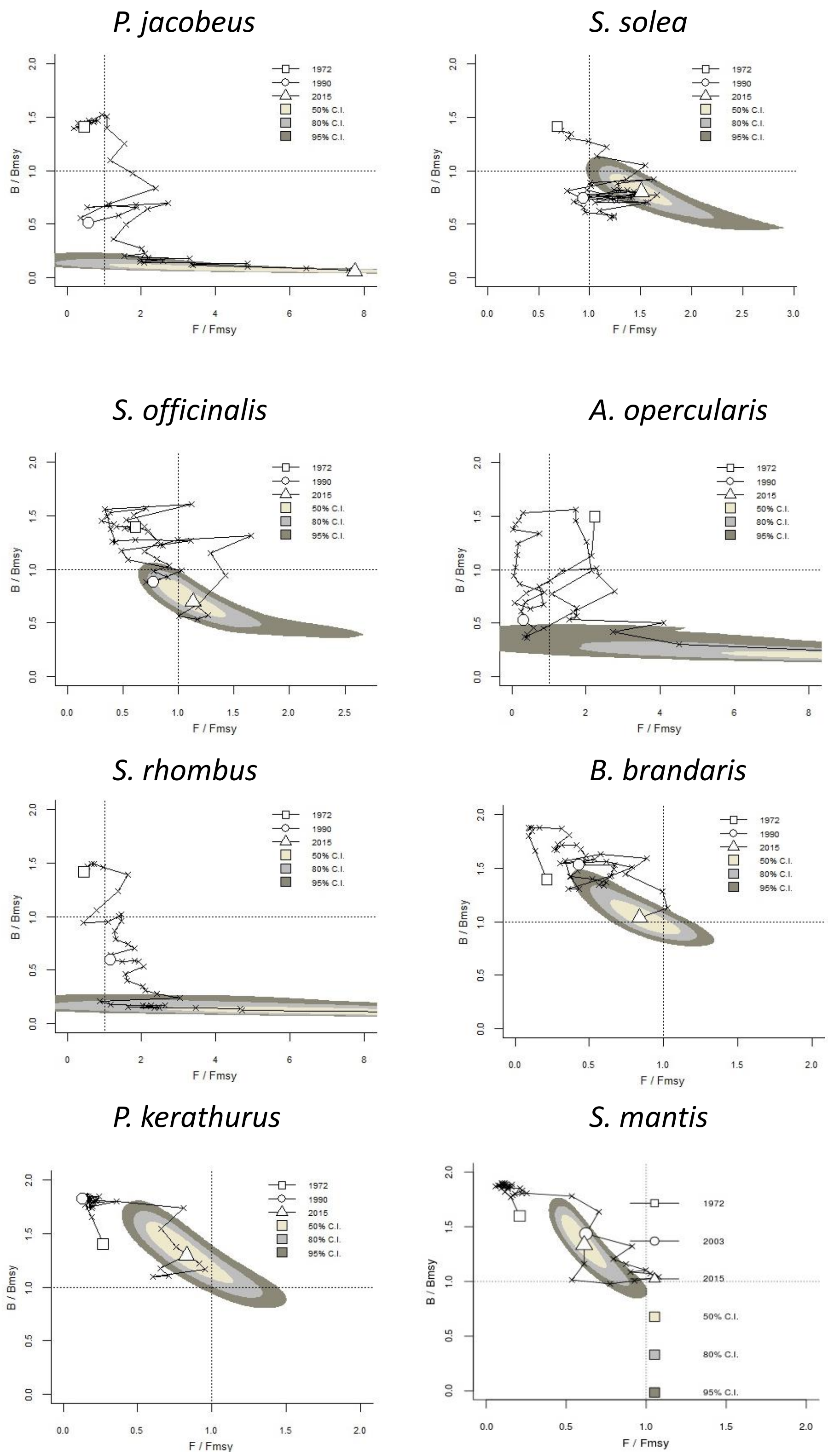

Figure 5.30 Kobe plot of stocks analysed in the Adriatic Sea case study. In each panel, B/B_{MSY} is plotted on the y-axis, while F/F_{MSY} is plotted on the x-axis. Horizontal and vertical lines indicate $F=F_{MSY}$ and $B=B_{MSY}$. The bottom right area indicates years where F>FMSY and B< BMSY. 50%, 80%, and 95% confidence intervals are given for 2015 estimates.

Mixed fisheries modelling

Simple multivariate analyses have been conducted on the Italian landing data by species, fleet segment and region of the period 2013-2015. The results suggest that that vessel using the rapido trawl (TBB) are grouped together. Therefore, the multi-fleet analysis has been focused on this activity, showing a geographical pattern (by region) in target stocks exploitation.

One realistic implementation of a HCR based on the CMSY estimates, can be obtained by setting relative fishing mortality proportional to the relative fishing mortality in 2016 ($F2016/F_{MSY}$) for each stock. Since F2016 is different for each stock, this solution proportionally reduces the effort on each stock, assuming that the fishing strategies and gears do not change. Thus, in this way a uniform reduction of the fishing hours (assuming a direct relationship between fishing mortality and fishing effort in hours) in a certain year affects each stock differently, depending on their exploitation rates. Forecast based on the following scenarios were carried out: $F = 0.5\ F2016/F_{MSY}$; $0.6\ F2016/F_{MSY}$; $0.8\ F2016/F_{MSY}$; $0.95\ F2016/F_{MSY}$, where F2016 depends on the stock (Figure 5.31).

Main results and conclusions

In all scenarios, only about the 80% of the stocks reach B_{MSY} in 2030, highlighting that for depleted stocks (*P. jacobaeus* and *S. rhombus*) B_{MSY} cannot be achieved just with a uniform reduction of effort (see second interim report for more details). A presentation of all simulation output is given in Annex 16.

Considering that most of the species targeted by the rapido trawl fishery are overexploited, a multispecies management plan for this fishery should be developed and implemented. The possible harvest control rules investigated within the multispecies analysis suggested that recovery of some severely depleted stocks is unlikely in the medium term. Therefore, a reduction of fishing effort should be accompanied by other management measures in order to allow a recovery of *P. jacobaeus* and *S. rhombus*. Spatial closures could be part of those measures. Although the multivariate analyses showed that the two species are often caught by the same vessels, the spatial distribution of the two species show little overlap. Hence, recovery of each species would require its own set of spatio-temporal closures.

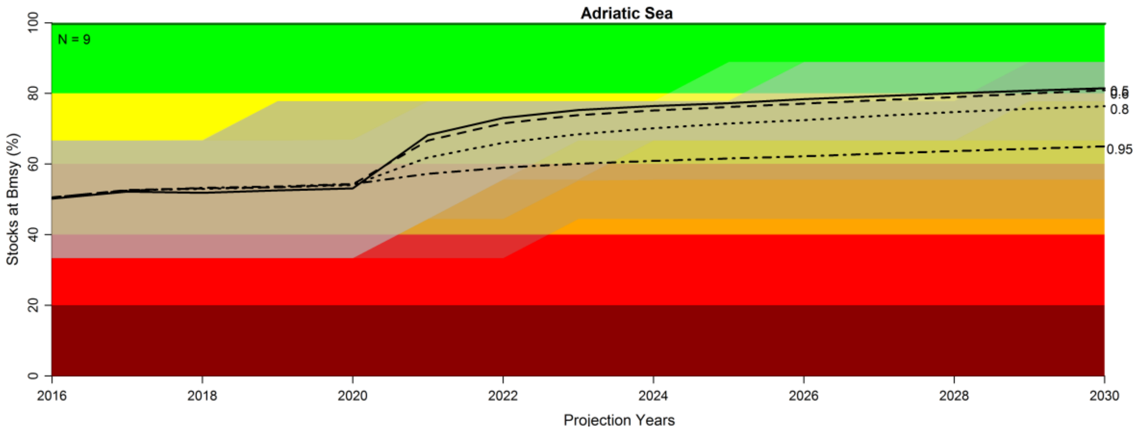

Figure 5.31 Percentage of stocks that will reach BMSY in the projection of stock biomasses up to 2030 according to the following scenarios: continuous line corresponding to an exploitation of F equal to 0.5 F_{MSY} for all stocks; dotted line corresponding to an exploitation of F equal to 0.6 F_{MSY} for all stocks; broken line corresponding to an exploitation of F equal to 0.8 F_{MSY} for all stocks; dashed line scenario corresponding to an exploitation of F equal to 0.95 F_{MSY} for all stocks. The different colours represent the percentage of stock that will reach B_{MSY} in 2030.

5.7. Aegean Sea case study

Executive summary

The report presents stock assessments of hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), striped red mullet (*Mullus surmuletus*) and pink shrimp (*Parapenaeus longirostris*). For these stocks the previous assessments are dated back to 2008 when they were assessed by means of deterministic surplus production models in the frame of the management plan for the Greek demersal trawl fisheries[22].

The assessments of red mullet and hake have been presented and endorsed during the 2017 Stock assessment session of the GFCM-SAC-WGSAD (Rome 13-18/11/2017). In the assessments presented in GFCM the catch data included also the aggregated production of the Turkish fisheries operating in the Aegean Sea (this was negligible in the case of hake). Given that the Turkish fisheries data were not available by fleet segment, the analysis and mixed fisheries exploitation scenarios included in the current report were based only in data from the Greek fisheries.

In summary, the stock assessments showed that hake was overfished and overfishing was taking place, while the other three stocks were in healthy condition and exploited in a sustainable way. The present findings are in line with past studies in different Mediterranean areas, suggesting that the hake stocks undergo severe over-exploitation, while the stocks of more coastal species seem to be in better condition (Cardinale and Scarcella, 2017; Vasilakopoulos *et al.* 2015). For the Aegean Sea, in particular, it has been suggested that the implementation of EC regulation 1967/2006, which bans bottom-trawl activities within 1.5 nautical mile off the coast, has resulted in the shift of fishing activities towards deeper waters; thus increasing fishing pressure onto slope resources, such as those of hake (Tserpes *et al.* 2016).

Under the current effort levels, the total yield from the fishery will be at 87% of the maximum multispecies yield but the hake stock will remain over-exploited, although not at a risk of collapse (equilibrium B will be around to 84% of B_{MSY}). Different combinations of effort can drive the hake stock to B_{MSY} levels. Within this objective, to achieve maximum multispecies yield without extreme effort changes for neither fleet segment, the effort of the coastal fleet has to be reduced by 30%. A relatively "pretty good yield" from all species (more than 75% of *MSY*) can be obtained by different effort combinations, mainly involving increase of the trawlers' effort and decrease of the effort of the coastal fisheries. Under this scenario, however, the hake stock will be severely overfished.

Context

The geographic boundaries of the study was the area GFCM GSA 22 (Aegean Sea) following FAO geographical areas (Figure 5.32).

The study includes the following stocks: hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), striped red mullet (*Mullus surmuletus*) and pink shrimp (*Parapenaeus longirostris*). These commercially important species were widely distributed in the studied area. The definition of stock structure was based on the GFCM geographical sub-areas (GSAs).

Following EC DCF 199/2008 there are fleet-métier combinations (area*vessel length category*gear) targeting demersal species in the area. There were otter trawlers (OTB) differentiated according to vessel length (OTB12_18, OTB18_24, OTB24_40) and coastal fisheries using static nets (GTR, GNS) and bottom longlines (LLS) differentiated again according to vessel length categories: 0-6m, 6-12m, 12-18m, 18-24m. Currently, the fisheries advice for the Greek waters follows an aggregated segmentation, in terms of vessel length and the type of coastal fisheries; thus including two main categories: otter trawls and coastal vessels. Figure 5.33 highlights which fleet segments were responsible for the main catch of the stocks included in the case study and their percentage catch shares.

[22] https://tinyurl.com/kb6qfzv

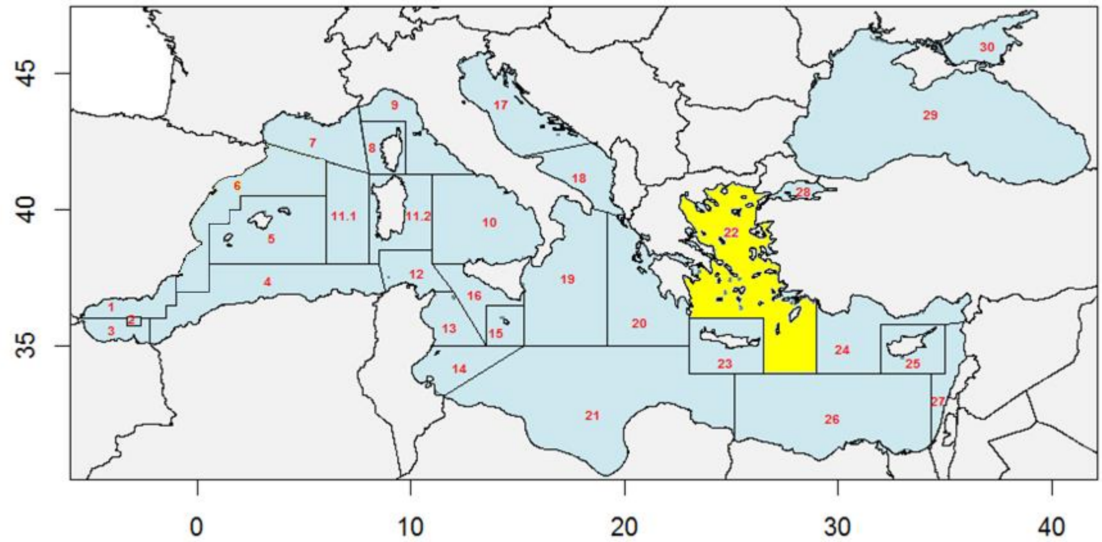

Figure 5.32 GFCM Geographical Sub-Areas (GSAs). In yellow, GSA 22, the study area of the Aegean case study.

Rationale for selection of fleets and stocks

This selection includes four of the most commercially important demersal stocks, whose landings' value corresponds to ca 75% of the total value of the demersal landings. It also follows the main target species identification for the GSA 22 demersal fisheries, in terms of landings and income, based on STECF (2015) and DCF data. The selected species were included in Annex III of the EU Reg. 1967/2006 (minimum landing sizes defined for the Mediterranean), and were the key-species considered in the enforced management plan.

Mixed fisheries issues

The demersal stocks of the Aegean Sea were exploited by bottom trawlers and small-scale coastal fisheries. These were typical multi-species fisheries and there were significant interactions among gears and fleet segments, since most of the main target species were exploited by more than one fishing technique or strategy. Thus, the main challenge was to identify exploitation patterns that maximize catches ensuring at the same time sustainable exploitation for all stocks according to EU targets.

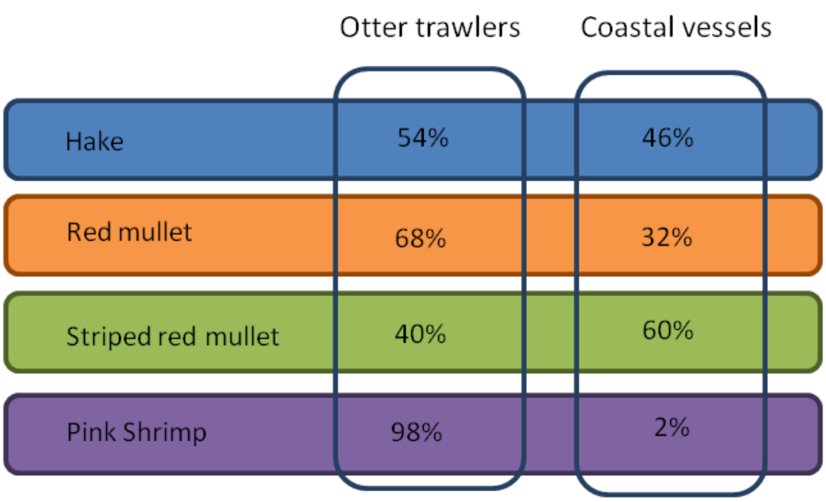

Figure 5.33 Description of mixed fisheries considered in the Aegean Sea case study. Blue frames indicate which stocks were caught by the different fleets. Percentages in the frames indicate the proportion of each stock that is caugh by the two fleets.

Stock assessments

A detailed presentation of the stock assessment conducted in the Aegean Sea case study during DRuMFiSH is given in Annex 17A.

The selected stocks have been previously assessed utilizing landings data obtained from the Greek Statistical Authority (HELSTAT), as well as DCF data. These assessments were dated back to 2008 and were accomplished in the frame of the existing management plan for the Greek demersal trawlers[23].

Given the available data, single-species stock assessments were based on a surplus production model implemented using SPiCT. SPiCT makes a state-space implementation of the surplus production model in continuous time. SPiCT was chosen as it provides a general framework (e.g. implementation in discrete or continuous time, likelihood or Bayesian approach, Pella-Tomlinson or Schaefer production curve, etc.) and has many functionalities (e.g. priors for both model parameter and dynamic components, convergence diagnostics, retrospective plots, etc.).

The assessments were based on (i) time series of landings from the Greek Statistical Authority (HELSTAT) for the period 1994-2016 and (ii) time series of abundance indices from the MEDITS trawl survey for those years the surveys took place (1994-2001, 2003-2006, 2008, 2014, 2016). For two of the stocks that were selected at the initial stage (anglerfish and squid), assessments were not finally performed as the landings data from the HELSTAT were not in these cases available at the species level.

The stock assessments showed that hake was overfished, while the rest of the stocks were exploited in a sustainable way. The Kobe plots (Figure 5.34) show the trajectories of biomass and fishing mortality (relative and absolute) for each species.

The adoption of interpolation techniques to fill important data gaps in the abundance index contributed in the reduction of uncertainty in model estimates. In the case of hake, the retrospective analysis indicated that the exclusion of the most recent observations had a rather substantial effect on biomass and mortality estimates for certain years, without, however, affecting the overall picture regarding stock status. Retrospective plots for the rest of the species did not show any pattern, suggesting model/data consistency and robustness of the results.

Mixed fisheries modelling

All demersal fisheries in GSA 22 (Aegean) were managed according to EU regulation 1967/2006, which foresees spatial fishery closures for the bottom trawlers, gear configuration specifications and minimum catching sizes. Additional national measures include a temporal (4.5 months) closure of the bottom trawl fisheries accompanied by certain localized spatio-temporal closures and a one-month (February) closure of the artisanal fisheries targeting hake. Detailed effort and catch composition data by fleet segment were hardly available due to the poor implementation of DCR/DCF in the last ten years. Nominal effort, expressed in terms of vessel number/capacity, and gear aggregated landings data were available from HELSTAT. Fishing mortality and biomass reference points based on F/F_{MSY} and B/B_{MSY} ratios were adopted in the frame of the EU adopted Management plan for the bottom trawlers[24]. A rate equal to one was considered as target for both ratios.

Due to data limitations, the mixed fisheries modelling was not based on an analytical framework (e.g. Fcube or FLBEIA). Future catch and stock biomass projections were carried out under different management schemes corresponding to different targets. Two major fleet segments (bottom trawlers and coastal vessels) were considered and the fishing mortality exerted on each stock was determined as a function of the catch share among the segments. Applying a management scenario consists of finding effort multiplier pairs that achieve scenario objectives in the medium term. The projections were carried out through simulations of a Pella-Tomlinson biomass production model parameterized

[23] https://tinyurl.com/kb6qfzv

[24] https://tinyurl.com/kb6qfzv

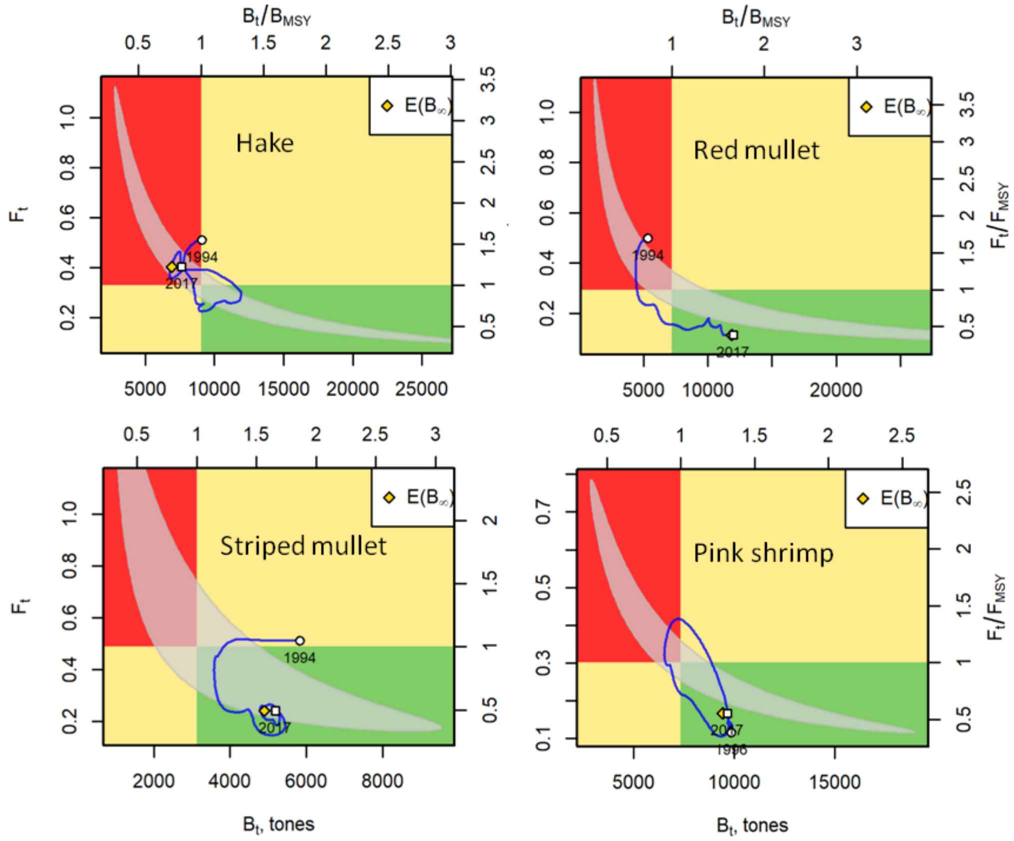

Figure 5.34 Historical stock status (Kobe plot) of the 4 stocks assessed using SPiCT in the Aegean Sea case study. In each of the panels, stock biomass is plotted on the x-axis, while fishing mortality is plotted on the y-axis. Red area indicates years where $F>F_{MSY}$ and $B< B_{MSY}$. Green area indicates years where $F<F_{MSY}$ and $B> B_{MSY}$. The numbers plotted at the start and end of each line indicate starting year and end year of time series.

according to the results of the stock assessments. The overall framework was based on production modelling approaches, inherently not considering fishing mortality by age or size. Besides constant catchability was assumed throughout the examined time period.

Five different management scenarios were considered. Except for the Status quo scenario (case A) and the unconditional maximization of the total fishery yield (case B) all other scenarios also consider the long term status of individual stocks:

- *Status quo.* Predicts how the catch and biomass of each species will develop if fishing effort, and consequently fishing mortality, remains at 2016 levels.
- *Maximum total yield.* Maximize the total yield of the fishery unconditionally, i.e. regardless of the condition of single stocks.
- *Pretty good single-species yields.* Require that all stocks will give a pretty good yield, i.e. yield that is between 80%*MSY* and *MSY* in the long term.
- *Healthy stocks.* Require that all stocks are healthy, i.e. their biomass is equal or above equilibrium B_{MSY} (i.e. $B > B_{MSY}$).
- *Safe stocks.* Require that all stocks' biomass is equal or above half the equilibrium B_{MSY} (i.e. $B > B_{MSY}/2$), minimizing the risk of stock collapse.

A detailed presentation of the mixed fisheries simulations conducted in the Aegean Sea case study during DRuMFiSH is given on Annex 17B. Figure 5.35 gives an example of spawning stock biomass trends under a mixed fisheries scenario that maximize the total yield while keeping all species equilibrium yield between 75% *MSY* and *MSY.*

Main results and conclusions

Currently, hake is fished beyond *MSY* levels while the rest of the stocks are fished well below *MSY* providing yields less than 80% *MSY* (pretty good yield). Still, the total yield of the fishery is within 80% of the maximum multispecies yield. The characteristic of the fishery is that pink shrimp is almost exclusively caught by otter trawlers, while all other species are caught by both fleets. In theory, maximization of the total multispecies yield can be achieved with complete closure of the coastal fishery and doubling the effort of the otter trawler fleet. This is due to the potential of increase of the shrimp catches and their high share in the total catch.

The objective of a relatively "pretty good yield" (ca 75% MSY) from all stocks can be achieved through different effort combinations, mainly involving increases of the trawlers' effort and decreases of the effort of the coastal fisheries. In this case, however, the hake stock will be severely overfished.

Different combinations of effort can drive the hake stock to B_{MSY} levels. In case, however, it is desirable to also achieve maximum multispecies yield, without extreme effort changes for either fleet segment, the effort of the coastal fleet has to be reduced by 30%.

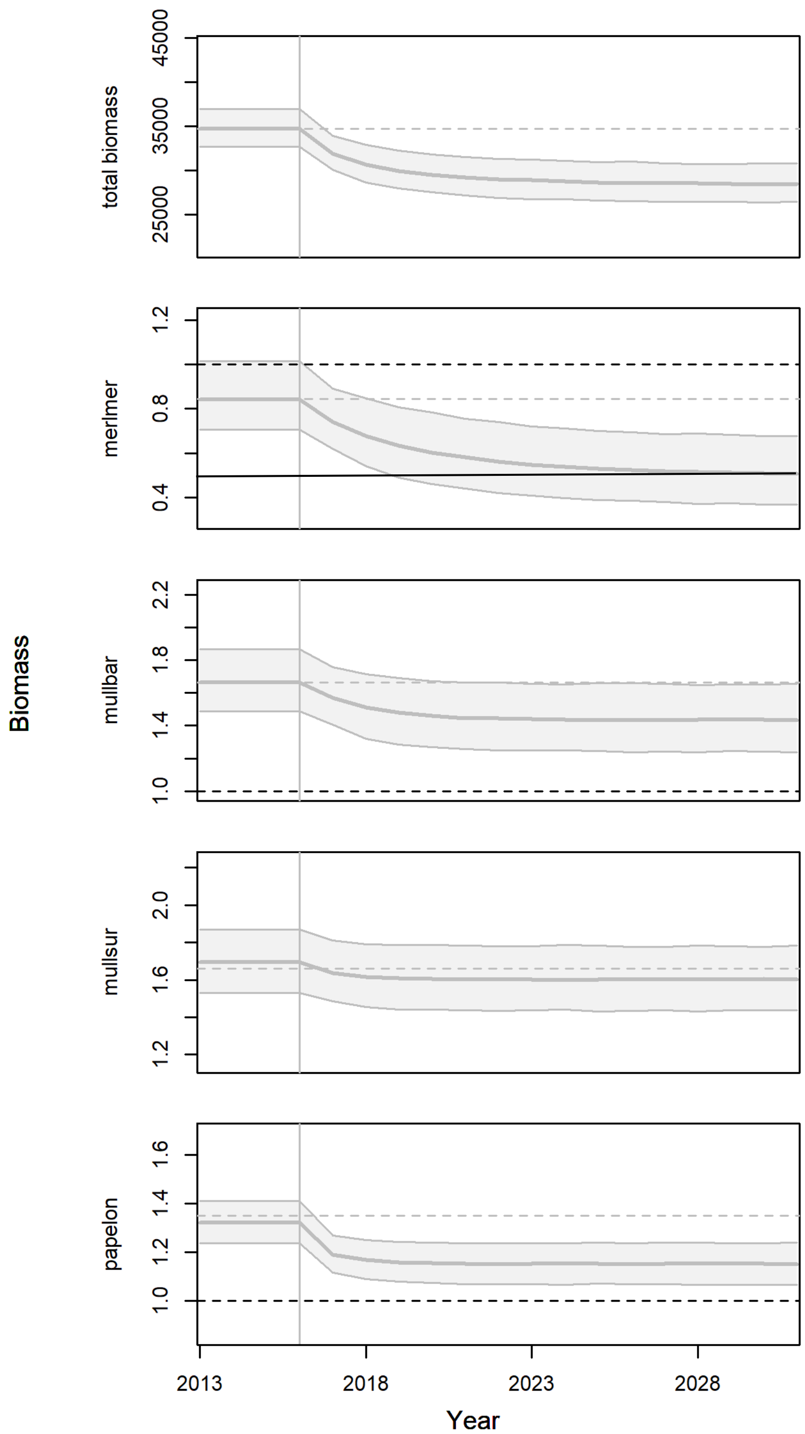

Figure 5.35 Example of future projection of total biomass (in tonnes) and relative biomass of the four species (hake (merlmer), red mullet (mullbar), striped red mullet (mullsur), and pink shrimp(papelon)). Gray areas indicate 95% confidence intervals for the set of effort multipliers that maximize the total yield while keeping all species equilibrium yield between 75% MSY and MSY. The observed biomass in 2016 is extended 3 years backwards to serve as a reference. The gray dashed line show the equilibrium biomass under the status quo scenario and the black dashed line is the relative biomass corresponding to B_{MSY}. The horizontal drawn black line in the Merluccius merluccius panel indicates 0.5 B_{MSY}.

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