Deliverable D4.2.1:

Developing a multispecific stocks MSE framework : English Channel and North Rajidae complex

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Introduction

This deliverable (D4.2.1) is part of SUMARiS Interreg project. D4.2.1 provides MSE tools and outcomes needed to understand species complex management implications. D4.2.1 science has been coordinated by IFREMER, with a strong involvement from ILVO and Wageningen Marine Research teams.

Fisheries stock assessment requirements are growing worldwide. However, important amounts of stocks does not have sufficient data for an analytical assessment (Costello *et al.*, 2012). The strong uncertainties associated with certain stock data and parameters interrogate stock assessments and their associated management measures performances (Rochet &, Rice 2009). Fishery stock management does not allow the implementation of environmental conditions needed to evaluate management procedures in controlled experimental conditions. These difficulties have fostered the development of mathematical tools to comprehensively simulate the dynamics of fishery systems using modeling frameworks such as MSE (Management Strategy Evaluation) (Smith, 1994).

A MSE consists in testing, using data simulations and management procedures in a closed loop, with several management measures applied to a stock and/or a fishery. The purpose of this approach is to evaluate objective achievements through management procedures and their sensitivity to stock/fishery parameterization assumptions. The aim of a MSE is not to determine what the best stock assessment method is according to the available data, but to calculate, using a simulation framework, the probability to achieve management targets (Punt *et al.*, 2016). In fishery management, it is impossible to obtain an exhaustive knowledge on stocks since many of them are categorized as Data-Limited Stocks, DLS (Costello *et al.*, 2012). Evaluating management measures should take into account data uncertainty and bias. To integrate this imprecision a MSE is used, based on data simulation by successive iterations. The purpose is to explore a more complex stock dynamic than the one simulated in DLM (Data Limited Models), and allows for multiple varieties of stock simulations through the variation of input parameters. This approach goes further than a sensitivity analysis of DLM stock assessment parameters (Kell *et al.*, 2007). Most of the simulation models within a MSE are age-based, whereas many stocks assessments do not use or provide demographic informations (ICES, 2019).

In the context of *Rajidae* stocks in the English Channel and the North Sea, the current management measures are limited to a common TAC for all of the species in ICES Division 3a, Subarea 4 and Division 7d. During the SUMARiS Interreg project, different stock assessment models have been applied to evaluate the status of these stocks. This data exploration highlighted important differences in stock status between species of the "*Rajidae*" complex (Amelot *et al.*, 2020). However, even if species specific stock assessment models are available, management measures considered for the next years will likely remain applicable to the whole group of species (SUMARiS Canterbury meeting, 2019).

Consequently, the MSE developed within SUMARiS has been designed to evaluate management measures performances in a multi-species framework. For this, an operating model was defined for each of the six commercial species within the *Rajidae* complex. After this first step, stock assessment models and a HCR (Harvest Control Rule) were implemented. They were selected in accordance with the whole management procedures that were preselected during the real data analysis. Finally, different type of mechanisms in TAC recommendations were simulated.

Materials and methods

Rajidae fishery management challenges

Management objectives associated with *Rajidae* stocks are quite far from the 'classic' management objectives. Indeed, one of the main concerns of fisheries is the impact of *Rajidae* management measures, through bycatch, on target flatfish species such as sole (*Solea solea)* and plaice (*Pleuronectes platessa*). The evaluation of this objective requires an ecosystemic MSE. Only multispecific MSE, restricted to the *Rajidae* complex, have been tested during the SUMARiS project.

Although *Rajidae* are bycatch species, they possess a high economic value with an average port price of 9 euro per kg (FranceAgriMer, France, Rungis Marée-Fraîche, 10/01/2020). In 2017, 2 284 tonnes of *Rajidae* were landed by the English Channel and North Sea international fishery. This represented a gross revenue of 2 055 600 euros (Figure 1).

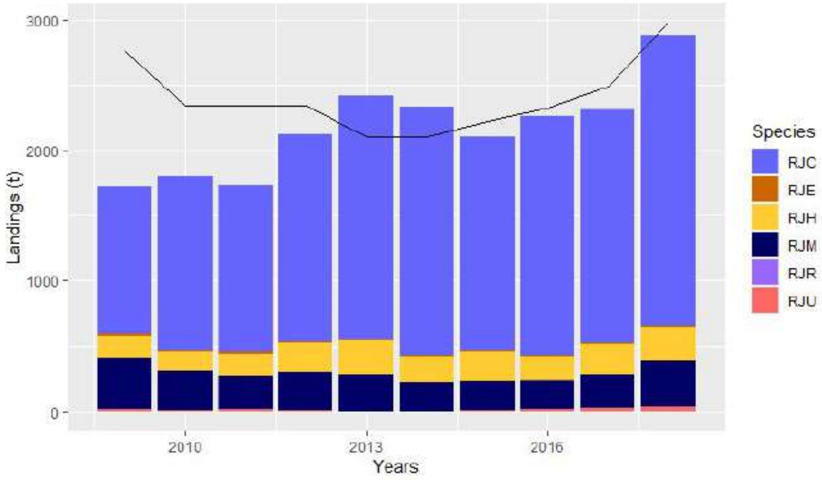


Figure 1 Landings per species in tonnes, from 2009 to 2018, with *Raja clavata* (RJC), *Raja microocellata* (RJE), *Raja brachyura* (RJH), *Raja montagui* (RJM), *Amblyraja radiata* (RJR), *Raja undulata* (RJU). TAC values are represented by the black line.

The *Rajidae* fishery is mainly composed of bottom trawlers (Figure 2). The French component of this fleet consisted of 89 exclusive trawlers and 316 non-exclusive trawlers in 2017, crewed by 659 and 976 fishermen, respectively (Ifremer, 2018). TAC management has been increasingly constraining since 2009, with a TAC that was reached almost every year since 2012 (Figure 1), although the impact on the fishing fleets may have been alleviated by the Landing Obligation Exemption that currently applies to *Rajidae* fisheries. This constraining TAC impacts the fishery in different ways, depending on fleet activity. So far, management measures have mainly impacted the most specialized fleets.

Due to their life history, skates and rays are considered to be particularly sensitive to overfishing (Dulvy *et al.*, 2000). As top predators, they play an important role in the top-down regulation of the entire ecosystem (Stevens *et al.*, 2000). *Rajidae* ecology, sensitivity and recent overexploitation has led to a need for a particularly cautious approach in regards to its management (Dulvy *et al.*, 2014).

In respect of management objectives relative to *Rajidae* stocks,two main objectives have been identified during Canterbury and Ramsgate SUMARis meetings; (1) Avoiding the decline of a species within the complex by identifying the most vulnerable one, and consequently steering clear of overfishing (2) Allowing for an optimization of the main commercial species, thornback ray (*Raja clavata*)

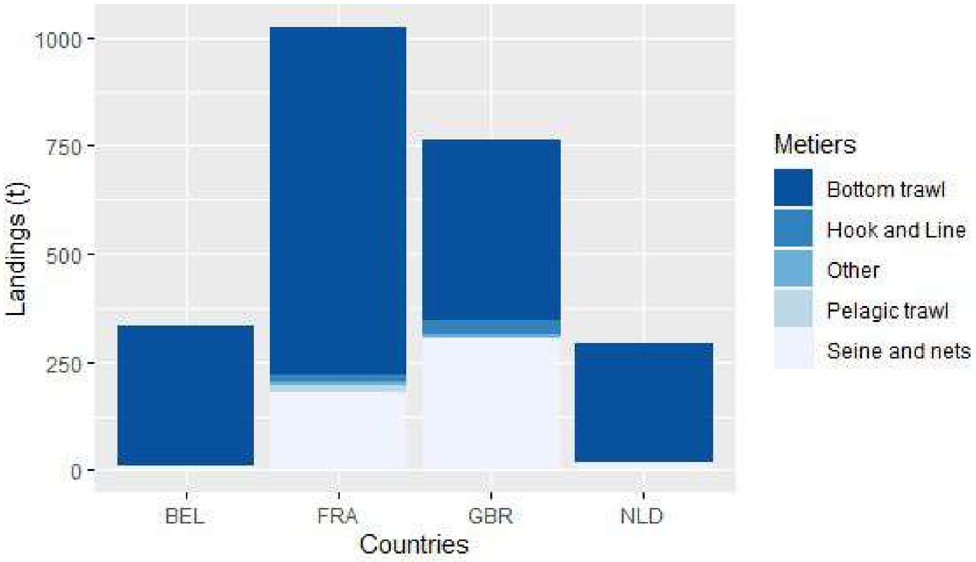


Figure 2 *Rajidae* landings per Fleet in 2017 in Belgium (BEL), France (FRA), Great Britain (GBR) and Nederland (NLD)

MSE framework and tools

The MSE is based on an operating model as well as management procedures. Each of these items are subdivided into components that all have their own dynamics. The objective of the operating model is to simulate real stock/fisheries dynamics (biomass, fishing mortality) as well as the observed stock data catches, landings and biomass indices. The operating model consists of four units (Figure 3). The Observation unit (1) processes uncertainty in model inputs (e.g., catch and abundance indices). The Stock unit (2) reproduces the populations' life history and stock dynamics. The Fishery unit (3) simulates the dynamics of fishing effort and pressure (fishing mortality) it exerts on stock biomass. Finally, the Implementation unit (4) mimics the extent to which scientific advice is adhered to by managers and eventually fishers (ICES, 2019).

The objective of the management procedure is to provide management recommendations (e.g., TAC) based on input data simulated by the operating model (OM). The management procedure consists of a stock assessment model and a Harvest Control Rule (HCR). Stock assessment model outputs consist of estimated biomass and fishing mortality time series, as well as biological reference points, of which MSY-based reference points are given a particular importance (B_{MSY}, F_{MSY}, MSY). A HCR benchmarks estimated fishing mortality and/or biomass against reference points to draw TAC recommendations for the following years.

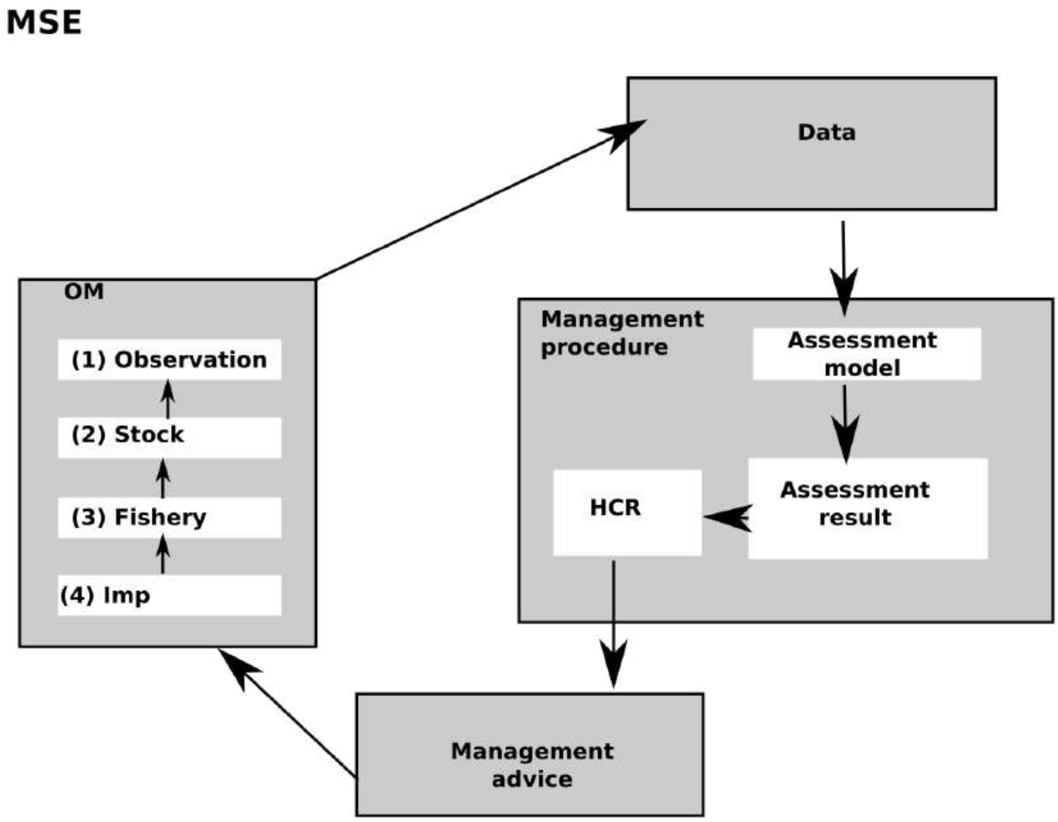


Figure 3 MSE conceptual framework, OM (Operating model), Imp (Implementation unit) Add OM (Operating Model) and Imp (Implementation unit) based on DLMtool and MSEtool packages structuration

The whole process is repeated for each year, and as many times as the number of data simulations, in our case 500 simulations (Figure 4). The outputs obtained from this method was a wide array of stock trajectories that allowed the identification of the management procedures that have the highest probability of failing, according to performance metrics.

The complexity and the number of relations between units that have to be parameterized in a MSE framework is time consuming (Butterworth, 2007, Bunnefeld *et al.*, 2011). Consequently, tools such as the FLR MSE or DLMtool have been developed to make MSE accessible and reproducible (Kell *et al.*, 2007; Carruthers & Hordyk, 2019; ICES, 2019). These recent tools are still in a development phase, but already provide possibilities to test a wide range of management procedures (ICES, 2019).

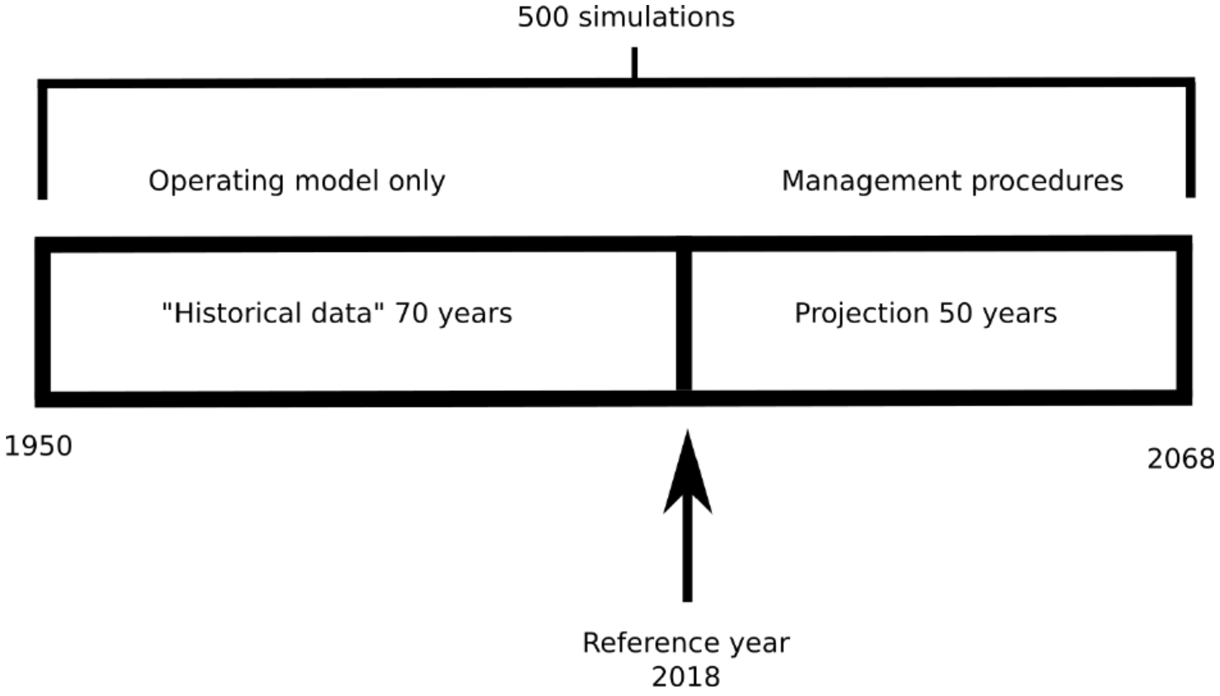


Figure 4 Simulation and iteration process within the MSE

Operating model definition

Stock unit

Within this stock unit, six species are represented : Thornback ray (*Raja clavata*), (*Raja microocellata*), (*Raja brachyura*), (*Raja montagui*), (*Amblyraja radiata*) and (*Raja undulata*). The Thornback ray (*Raja clavata*) is the most important *Rajidae* species in terms of biomass and landings in the English Channel and North Sea area. Moreover, the number of publications on this species is more important compared to other *Rajidae*. Thornback ray's biological parameters were drawn from Sys (unpublished data) and Rens *et al.* (2019). To complete the data used within the stock unit, *Raja clavata* life history parameters were used. Differences in length at age, maturity and discards, have been accounted for when available from the literature (Holden, 1972, Du Buit, 1977, Ellis *et al.*, 2012, McCully *et al.*, 2012, Marandel, 2018), and Fishbase (Appendix 1, Stocks).

As *Rajidae* are DLS, stock units should be considered with caution. Other sources and approaches should be taken into consideration to build adequate stock units highlighting life history differences between species. This first MSE framework gives the opportunity to identify which primary parameter needs to be precise.

Data collection and expert knowledge elicitation should be prioritized to improve *Rajidae* complex MSE performances.

Fleet unit

Rajidae catches are mainly driven by bottom trawl fleets in the English Channel and North Sea area. Data on for single Fleet fishery (1950-2018), with a decreasing effort in recent years, has been input. Vulnerability and selectivity data have been set according to the French observer program, Obsmer (Appendix 1, Fleet).

Observation unit

Considering that landings data were reported at a species specific level from 2009, and that *Rajidae* discards information are of poor quality, catch data were considered imprecise. Consequently, an observation unit has been built by taking into account precise and unbiased information for abundance indices and life history parameters, but imprecise information on catch data for all species. To obtain a more realistic observation unit, these approaches should be crossed with a first imprecise observation from the beginning of the time series up until 2009, and a precise observation unit from 2009 up to the current year.

Implementation unit

Even if constraining management measures did not exist before 2009 in the area, the implementation unit was built upon the hypothesis that all management measures were perfectly respected throughout the studied period. Indeed, there is information that would suggest that management measures have been disrespected after their implementation. Moreover, in order to obtain a more realistic implementation unit, this unit should be split between the given time periods that are the no-management (1980-2008) and the management (2009-2018) period.

Operating model simulations

According to these different units fishing mortality and biomass during the historical year were simulated (Appendix 2). All simulations indicated an important decrease in fishing mortality during the last years.

Management procedure definition

Stock assessment

Three DLS assessment methods have been tested during SUMARiS (Amelot *et al.*, 2020): CMSY, SPicT and a multispecies State Space Bayesian model (SSBM).

SPicT is used by the ICES and is also one of the MSEtool stock assessment methods. MSEtool SPicT results were compared with previous *Rajidae* SPicT assessment results. *Rajidae* SPicT assessment results were used as a basis to parameterize the MSEtool SPicT model used in this MSE.

HCR

A HCR was built using the ICES approach, for category 3 and 4 data limited stocks (ICES, 2017) (Figure 5). The ICES's recommendation is to define $B_{trigger;}$ the biomass value that triggers the management action at $0.5B_{MSY}$. When the stock biomass in the last year of the stock assessment is over $B_{trigger}$, the TAC recommendation is consistent with F_{MSY}. When the biomass in the last year of the stock assessment is below $B_{trigger}$, fishing mortality is linearly reduced and the recommended TAC is aligned accordingly. A second key value, the fishing limit, is obtained when this linear reduction reach a fishing mortality of 0.

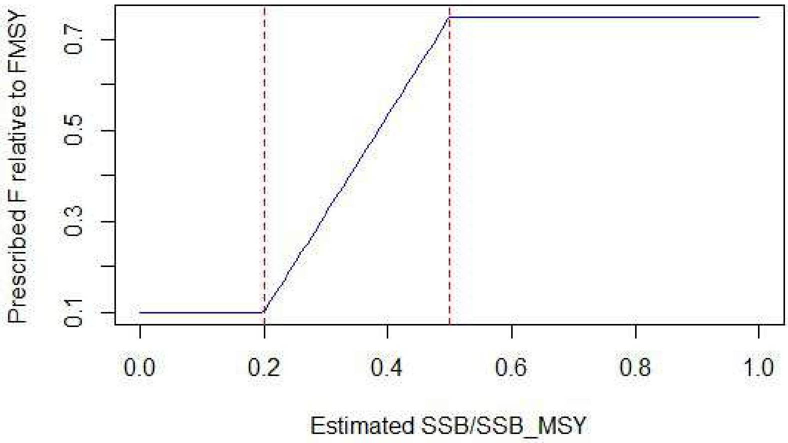


Figure 5 Linearly ramped HCR based on ICES WKMSYCat34 recommendations, from left to right, first red line: fishing limit, second red line $B_{trigger}$

Rajidae MSE scenarios

The DLMtool tool, with the MSEtool and DLMextra extensions, was used to conduct the MSE. This tool was simultaneously used by the ILVO to test different management procedures, based on analytical assessments applicable to Thornback ray. Four MSE scenarios have been tested (Appendix 3):

- A SPicT assessment method combined to a HCR for all *Rajidae* species separately (MSE 1)
- A SPicT assessment method combined to a HCR, for all species separately, but with a TAC recommendation applicable to the whole *Rajidae* complex (MSE 2)
- A SPicT assessment method combined to a HCR, applied separately to *Raja clavata* and grouping all other *Rajidae* species (MSE 3).
- A complex approach SPicT-HCR grouping all *Rajidae* species, including the thornback ray during the stock assessment phase and taking into consideration the unique TAC recommendation (MSE 4).

The MSE will highlight the best strategies, in order to avoid overexploitation of sensitive species. Moreover, a MSE will evaluate the extent to which a multi-specific approach, on *Rajidae* stock assessment and management procedures, might increase overfishing risks. Furthermore, this approach will quantify the economic impact of the stocks and simulate the best layout, in terms of grouped species within the complex, so as to obtain an optimized exploitation of the thornback ray (*Raja clavata*) for short-term and long-term yields. Finally, the MSE results will indicate inter-annual variability in yield and provide some cues on the employment stability induced by the different management procedures.

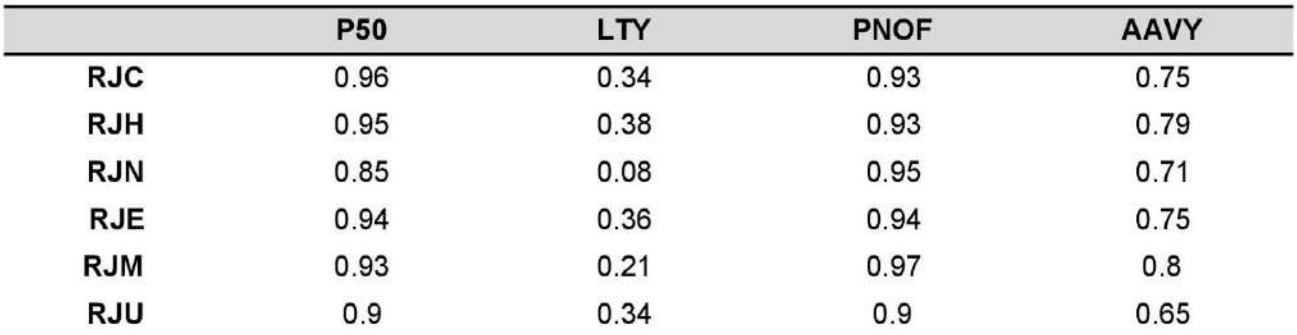
Results

One Operating Model has been generated (Appendix 3). Four MSE were run for this Operating Model (MSE1 – MSE4, as described above). Potential convergence issues were not tested due to time limitations.

Species specific assessments and recommendations (MSE 1)

Performance metrics are high for all species according to species specific assessment and recommendation, with less than 15 % of the simulations giving a spawning biomass below 50 % of the B_{MSY} (Table 1). This approach allows for long-term optimization of the yield for all species witha yield superior to the reference yield (yield in the last year of historical simulations) (Table 1).

Table 1 MSE 1 performance metrics summary, species specific assessments and recommendations; P50: probability of spawning biomass being greater than 50 % B_{MSY}, years 1 to 50; LTY: probability of average yield being greater than 50 % the yield in the last year of historical simulations, years 1 to 50; PNOF: probability of fishing mortality being under F_{MSY}, years 1 to 50; AAVY, probability of average annual variability in yield being under 0.2, years 1 to 50. RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata*, RJM, *R. montagui*, RJU, *R. undulata*.



	P50	LTY	PNOF	AAVY
RJC	0.96	0.34	0.93	0.75
RJH	0.95	0.38	0.93	0.79
RJN	0.85	0.08	0.95	0.71
RJE	0.94	0.36	0.94	0.75
RJM	0.93	0.21	0.97	0.8
RJU	0.9	0.34	0.9	0.65

Interspecies comparison using Kobe plot outputs shows that this management procedure is performing best for *R. montagui* and worst for *R. undulata* (Figure 6).

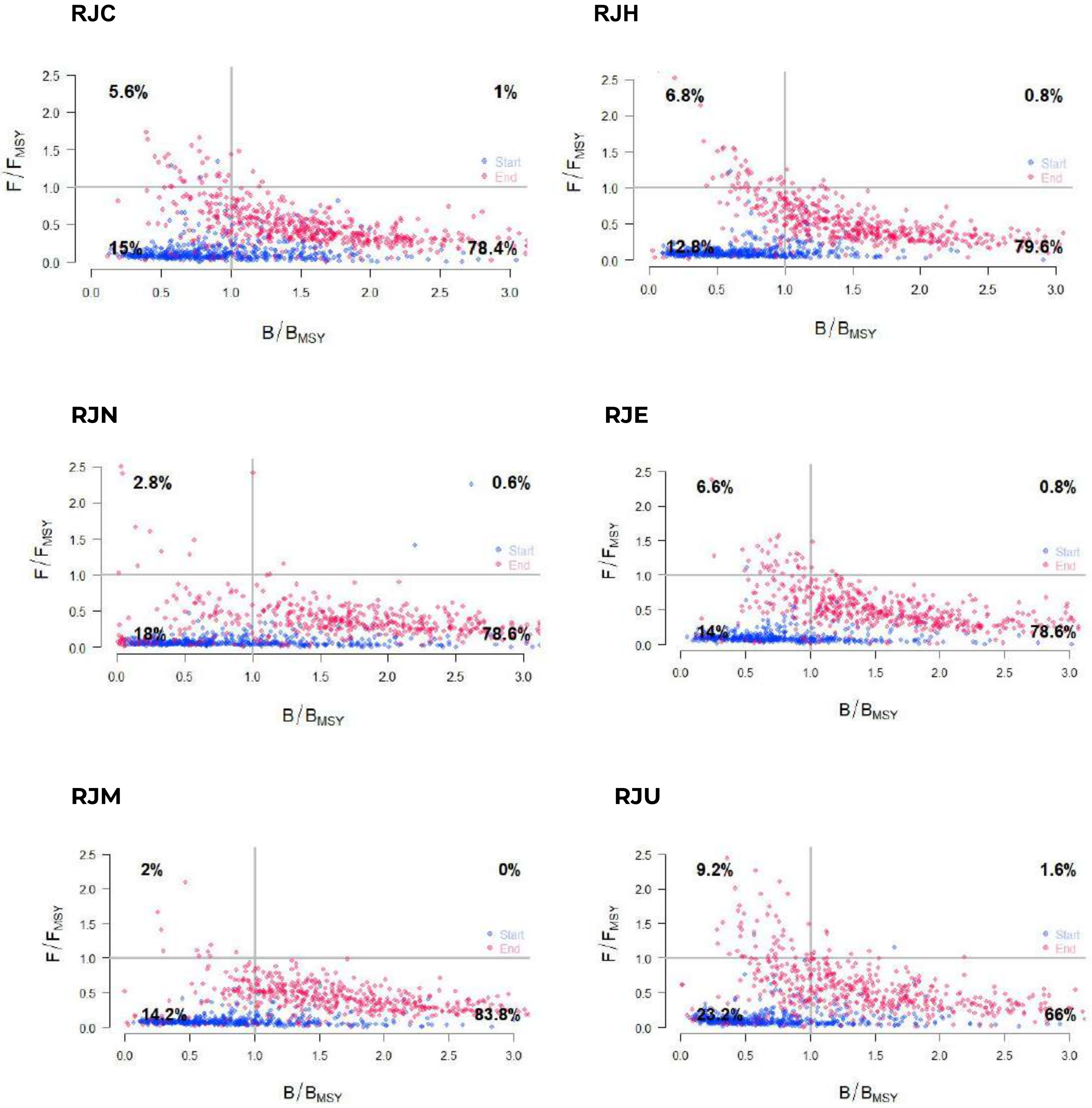
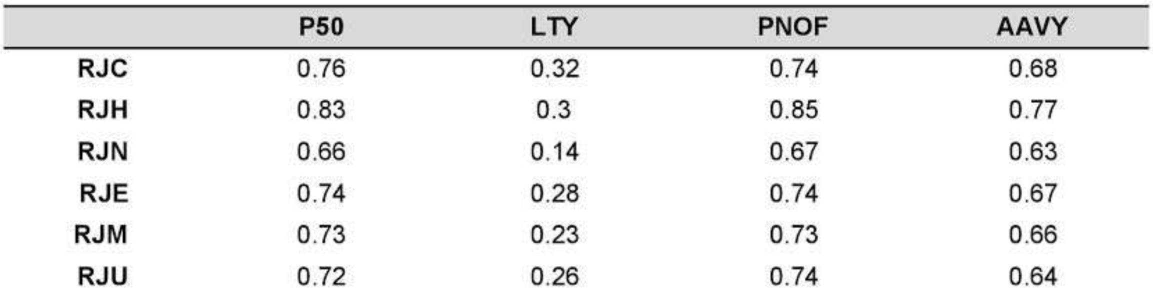


Figure 6 Kobe plot MSE 1 individual assessments and individual recommendations, RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata,* RJM, *R. montagui*, RJU, *R. undulata*, relative biomass SSB/SSBMSY compared to relative fishing mortality F/FMSY. Start, reference year 2018, End, end of the simulation 2068.

Species specific assessments complex recommandations (MSE 2)

This approach shows a higher probability of spawning biomass being below 50 % of B_{MSY} (Table 2). The long-term yield is higher for *L. naevus* and *R. montagui*. However, it is not the case for the most commercialized species *R. clavata* and *R. brachyura* (Table 2).

Table 2 MSE 2 performance metrics summary, species specific assessments and complex recommendations; P50: probability of spawning biomass being greater than 50 % B_{MSY}, years 1 to 50; LTY: probability of average yield being greater than 50 % the yield in last year of historical simulation, years 1 to 50; PNOF: probability of fishing mortality being under F_{MSY}, years 1 to 50; AAVY, probability of average annual variability in yield being under 0.2, years 1 to 50. RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata*, RJM, *R. montagui*, RJU, *R. undulata*.



	P50	LTY	PNOF	AAVY
RJC	0.76	0.32	0.74	0.68
RJH	0.83	0.3	0.85	0.77
RJN	0.66	0.14	0.67	0.63
RJE	0.74	0.28	0.74	0.67
RJM	0.73	0.23	0.73	0.66
RJU	0.72	0.26	0.74	0.64

Comparison between species using Kobe plot shows a best performance for *R. brachyura*, and the worst for *L. naevus* (Figure 7). Generally, for all other species, the probabilities of $SSB < SSB_{MSY}$ and of $F > F_{MSY}$ are between 35 % and 40 %.

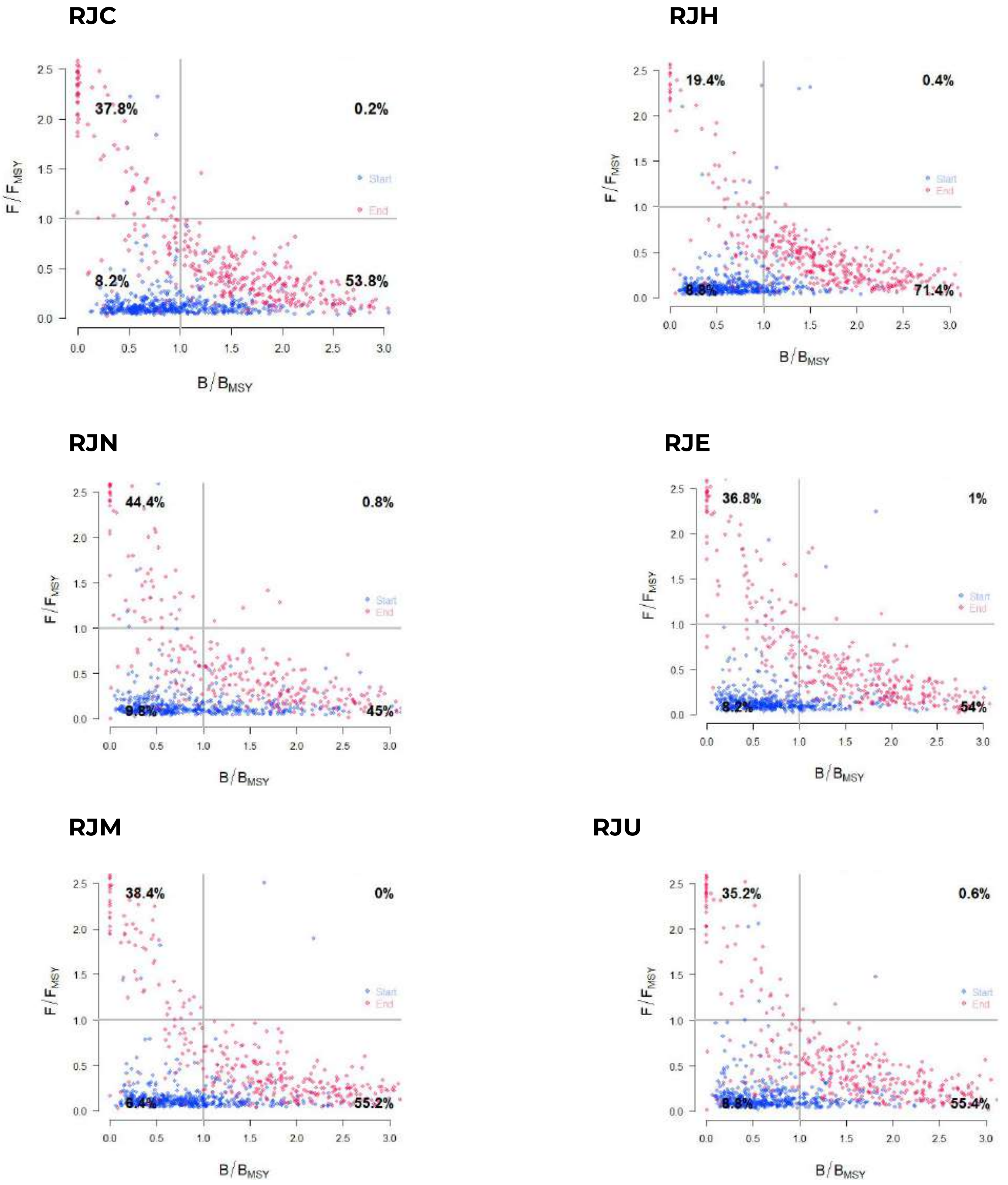
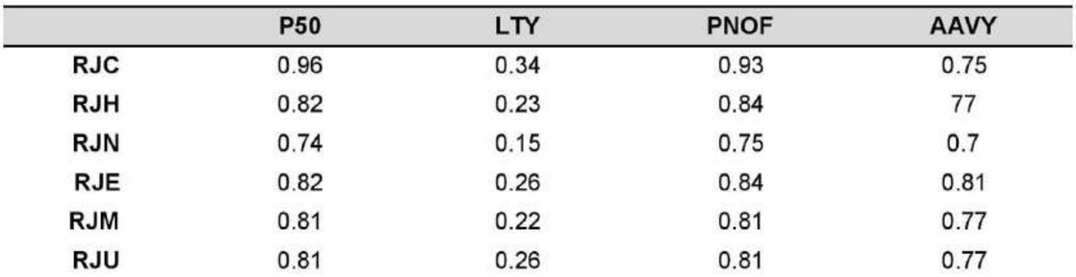


Figure 7 Kobe plot MSE 2 individual assessments and complex recommendation, RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata*, RJM, *R. montagui*, RJU, *R. undulata*, relative biomass SSB/SSB$_{MSY}$ compared to relative fishing mortality F/F$_{MSY.}$ Start, reference year 2018, End, end of the simulation 2068.

Species specific assessments and recommandation *R.clavata* and complex *Rajidae* (MSE 3)

MSE 3 performs similarly to MSE 1 for *R. clavata*. However, it seems to be the worst performing strategy for *R. brachyura*. Overall the probability of SSB < SSB_{MSY} is below 30 % for all species (Table 3).

Table 3 MSE 3 performance metrics summary, species specific assessments and complex recommendations; P50: probability of spawning biomass being greater than 50 % B_{MSY}, years 1 to 50; LTY: probability of average yield being greater than 50 % the yield in last year of historical simulation, years 1 to 50; PNOF: probability of fishing mortality being under F_{MSY}, years 1 to 50; AAVY, probability of average annual variability in yield being under 0.2, years 1 to 50. RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata*, RJM, *R. montagui*, RJU, *R. undulata*.



	P50	LTY	PNOF	AAVY
RJC	0.96	0.34	0.93	0.75
RJH	0.82	0.23	0.84	77
RJN	0.74	0.15	0.75	0.7
RJE	0.82	0.26	0.84	0.81
RJM	0.81	0.22	0.81	0.77
RJU	0.81	0.26	0.81	0.77

The overall overfishing probability, when stock biomass is below B_{MSY} and fishing mortality is over F_{MSY}, is close to 30 % for all species except *R. clavata*.. Excepting *R. brachyura*, the overall fishing probability is at a lower compared to MSE 2 (Figure 8).

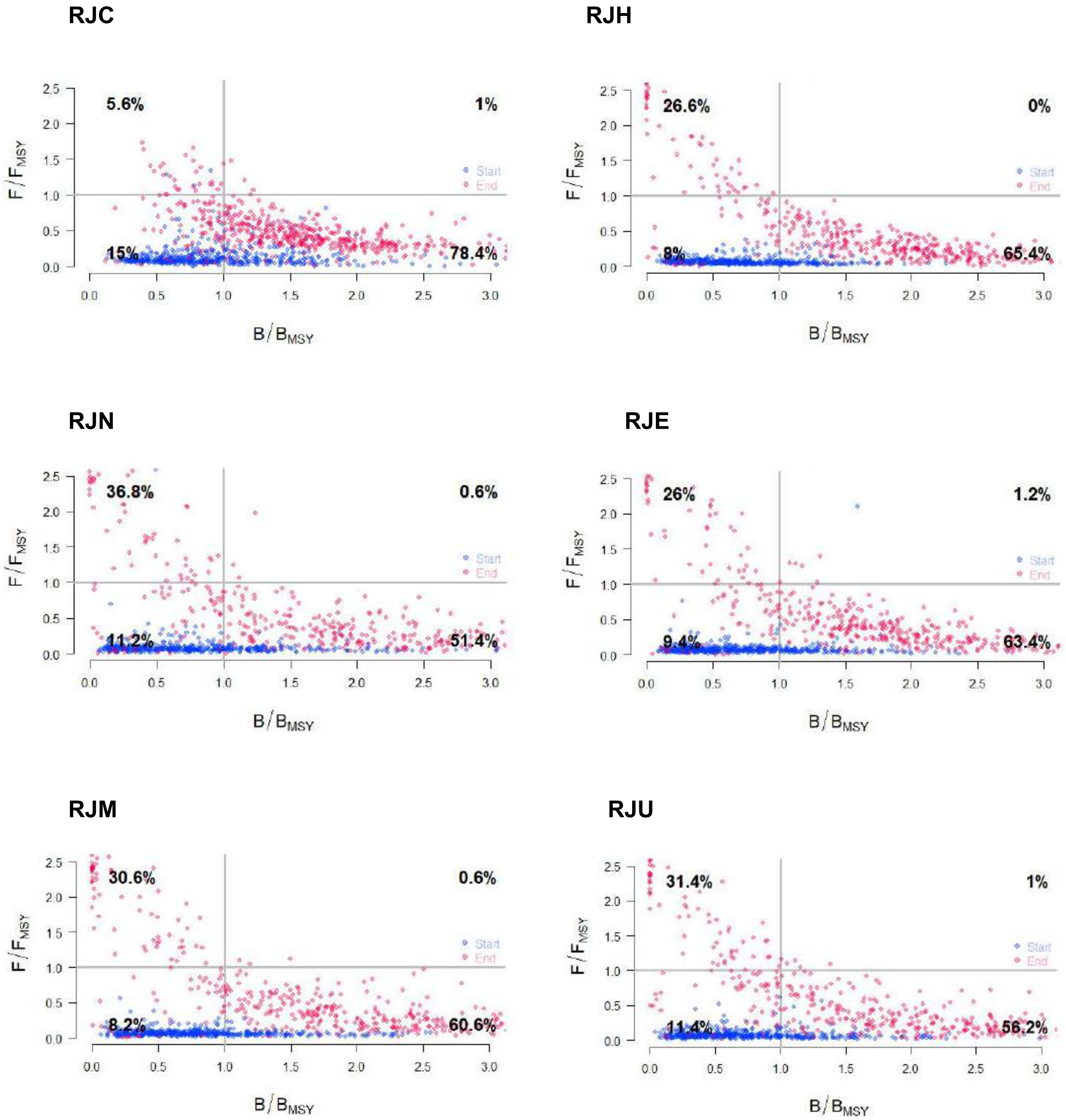


Figure 8 Kobe plot MSE 3 : individual assessment and recommendation for *R. clavata* and complex assessment and recommendation for other *Rajidae* species, RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata*, RJM, *R. montagui*, RJU, *R. undulata*, relative biomass SSB/SSB_{MSY} compared to relative fishing mortality F/F_{MSY}. Start, reference year 2018, End, end of the simulation 2068.

Complex assessment and recommendation (MSE 4)

Finally, MSE 4, with complex assessment and complex recommendation, performs the best in terms of yield stability over time, with a variation of more than 10 % compared to the other MSEs. It also falls in second place when considering the probabilities of having B > 50 % B_{MSY} and F < F_{MSY} (Table 4).

Table 4 MSE 4 performance metrics summary, species specific assessments and complex recommendations; P50: probability of spawning biomass being greater than 50 % B_{MSY}, years 1 to 50; LTY: probability of average yield being greater than 50 % the yield in last year of historical simulation, years 1 to 50; PNOF: probability of fishing mortality being under F_{MSY}, years 1 to 50; AAVY, probability of average annual variability in yield being under 0.2, years 1 to 50. RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata*, RJM, *R. montagui*, RJU, *R. undulata*.

	P50	LTY	PNOF	AAVY
RJC	0.89	0.31	0.85	0.87
RJH	0.89	0.25	0.89	0.87
RJN	0.77	0.15	0.76	0.77
RJE	0.85	0.27	0.84	0.84
RJM	0.83	0.21	0.82	0.82
RJU	0.83	0.25	0.82	0.79

Comparisons based on the Kobe plot underlines a probability of overfishing, when stock biomass is below B_{MSY} and fishing mortality is over $F_{MSY,}$ close to that obtained with MSE 3, except for *R. clavata* and *R. brachyura* (Figure 9).

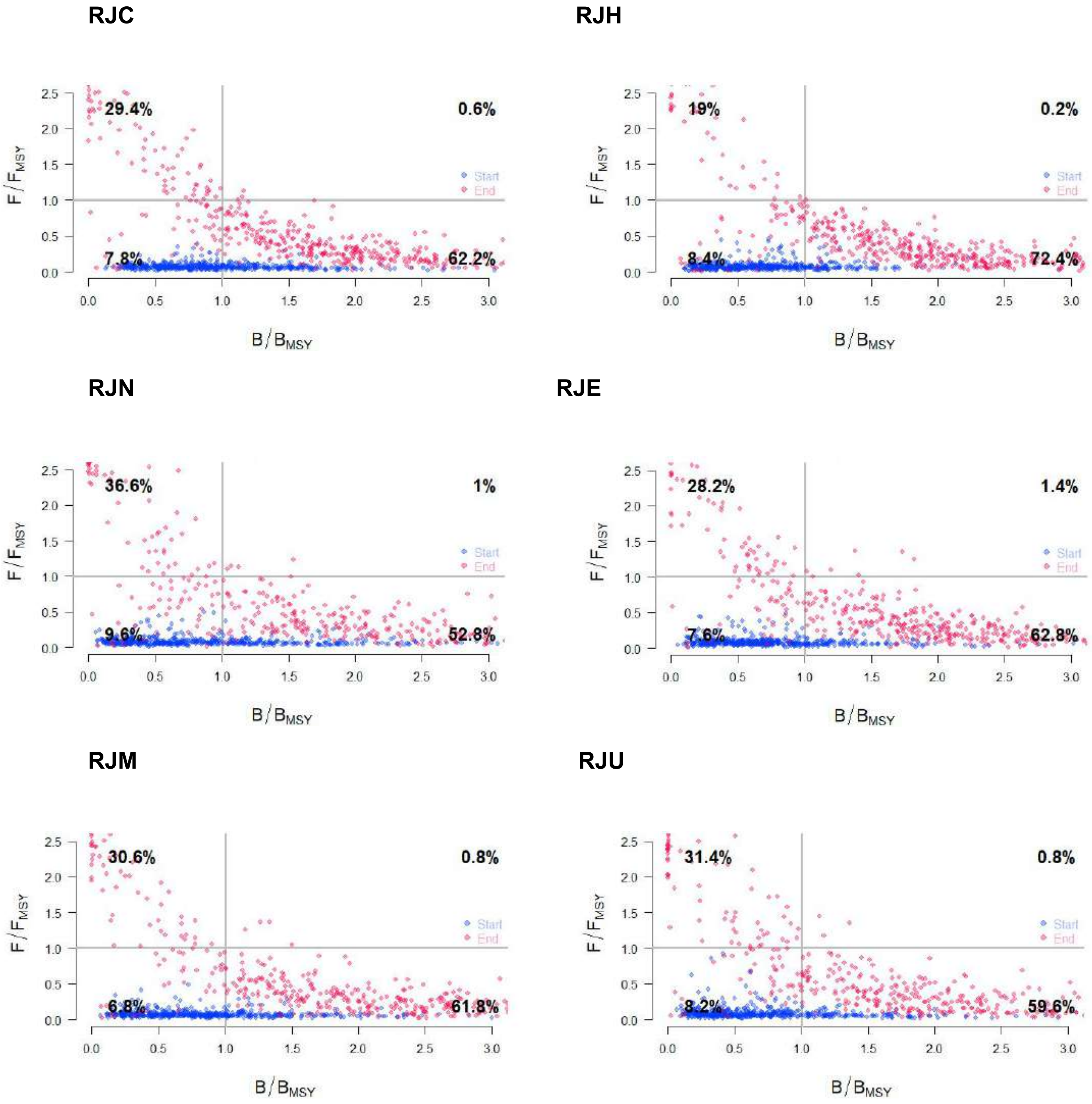


Figure 9 Kobe plot MSE 2 complex assessment and recommendation, RJC, *R. clavata*, RJH, *R. brachyura*, RJN, *L. naevus*, RJE, *R. microocellata*, RJM, *R. montagui*, RJU, *R. undulata*, relative biomass SSB/SSB$_{MSY}$ compared to relative fishing mortality F/F$_{MSY}$. Start, reference year 2018, End, end of the simulation 2068.

Discussion

Potential data improvement

The best performing MSE, meaning the one that takes into account all performance metrics, is the one that uses species specific assessment and recommendation. However, this management procedure does not seem to be the most likely to be implemented. Indeed,current data availability makes it difficult to obtain a performing SPicT assessment for all species.

These stock assessment limitations could be reduced in a few years with species specific landings reports and improved discards estimations. Until appropriate length and age informations are available, the SPicT approach will be favored. When long series of data become available, concerning mainly the three most abundant species *R. clavata*, *R. brachyura* and *R. montagui*, analytical stock assessments may be a promising alternative.

Taking into account the current data available, which represents over 50 years of complex landings and 30 years of abundance indices for all species, a complex stock assessment seems to be the best performing management procedure for now. However, our MSE approach makes the hypothesis that catches are supposed to be proportional to the actual species specific biomass proportion, when TAC recommendations are grouped.

Multispecific versus monospecific

To conduct grouped stock assessments and avoid data limitation for species specific data, issues related to the implementation of management measures must be quantified. Indeed, it is easier to give recommendations on the level of the complex. Unfortunately, these recommendations only make sense if the landings by species are proportional to the relative abundance of these species. SUMARiS D1.3.1 brings into light landings disparity between species. The main cause of this difference seems to be linked to the species' size. Indeed larger species, like *R. brachyura,* are less discarded than other species such as *R. clavata* and *R. montagui*. Consequently, in the case of a grouped TAC recommendation, *R. brachyura*'s relative fishing mortality is higher compared to that of the other species of the complex. To avoid the impact of this retention pattern on stock abundances, the solution would be to use a complex stock assessment, a complex recommendation, and a species specific landing size.

Further perspectives

All of the hypotheses linked to the objectives (1) and (2): Avoiding the decline of a species within the complex by identifying the most vulnerable one, and consequently steering clear of overfishing. Allowing for an optimization of the main commercial species, thornback ray (*Raja clavata*);are not yet measurable using the available MSE tools. The development of a new tool specific to these stocks and relative issues would allow a more accurate evaluation of the potential impacts of management measures on *Rajidae* stocks and fisheries. Furthermore, data used as input for most of the species, except *R. clavata*, are subject to caution. A detailed recollection of other stock data should be pursued in order to obtain a more realistic stock unit. Moreover, differences in retention patterns should be carefully simulated to assess the relative impact of landings and discards on the different species.

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Appendices

Appendix 1 Operating models

Stocks

Table 1 summary of stock information, refer to DLMtool (Carruthers & Hordyk, 2015) for parameters.

Name	RJC3a47d		RJU3a47d		RJH3a47d		RJM3a47d		RJN3a47d		RJE3a47d	
Common_Name	Thornback ray		Undulate ray		Blonde ray		Spotted ray		Cuckoo ray		Small-eyed ray	
Species	Raja clavata		Raja undulata		Raja brachyura		Raja montagui		Leucoraja naevus		Raja microocellata	
maxage	16.00		21.00		15.00		18.00		14.00		14.00	
R0	1000.00		1000.00		1000.00		1000.00		1000.00		1000.00	
M	0.10	0.30	0.10	0.30	0.10	0.30	0.10	0.30	0.10	0.30	0.10	0.30
Msd	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20
h	0.50	0.70	0.50	0.70	0.50	0.70	0.50	0.70	0.50	0.70	0.50	0.70
SRrel	1.00		1.00		1.00		1.00		1.00		1.00	
Perr	0.20	0.40	0.20	0.40	0.20	0.40	0.20	0.40	0.20	0.40	0.20	0.40
AC	0.10	0.90	0.10	0.90	0.10	0.90	0.10	0.90	0.10	0.90	0.10	0.90
Linf	85.00	140.00	112.00	122.00	120.00	130.00	68.00	73.00	68.00	72.00	120.00	150.00
K	0.13	0.21	0.11	0.25	0.18	0.20	0.17	0.19	0.05	0.15	0.05	0.15
t0	-0.65	-0.55	-0.55	-0.01	-0.70	-0.90	-0.40	-0.30	-0.50	-0.40	-2.50	-0.05
LenCV	0.08	0.12	0.08	0.12	0.08	0.12	0.08	0.12	0.08	0.12	0.08	0.12
Ksd	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01
Linfsd	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.05
L50	58.00	71.00	80.00	85.00	78.00	83.40	50.90	62.50	50.80	53.60	58.90	77.90
L50_95	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
D	0.10	0.50	0.05	0.40	0.05	0.40	0.05	0.40	0.05	0.40	0.05	0.40
a	0.0054		0.004		0.0027		0.004		0.003		0.003	
b	3.05		3.14		3.26		3.15		3.17		3.22	
Size_area_1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Frac_area_1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Prob_staying	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Fdisc	0.40	0.60	0.40	0.60	0.40	0.60	0.40	0.60	0.40	0.60	0.40	0.60

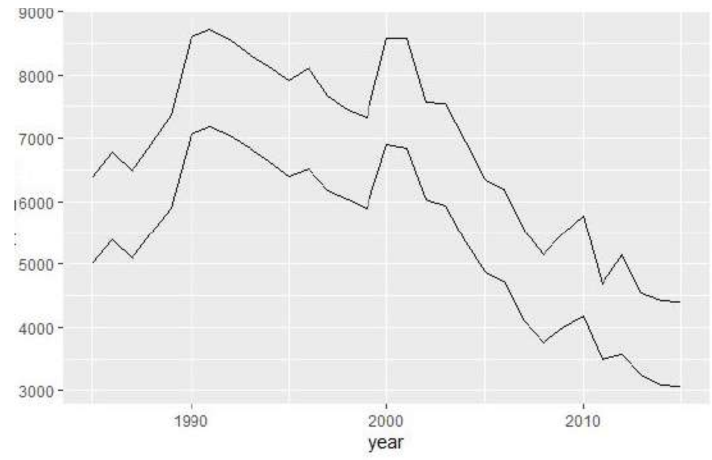

Figure 1 Fishing Effort in hours in division 3a47d from 1980 to 2019, hours trawling.

Appendix 2 Operating model data

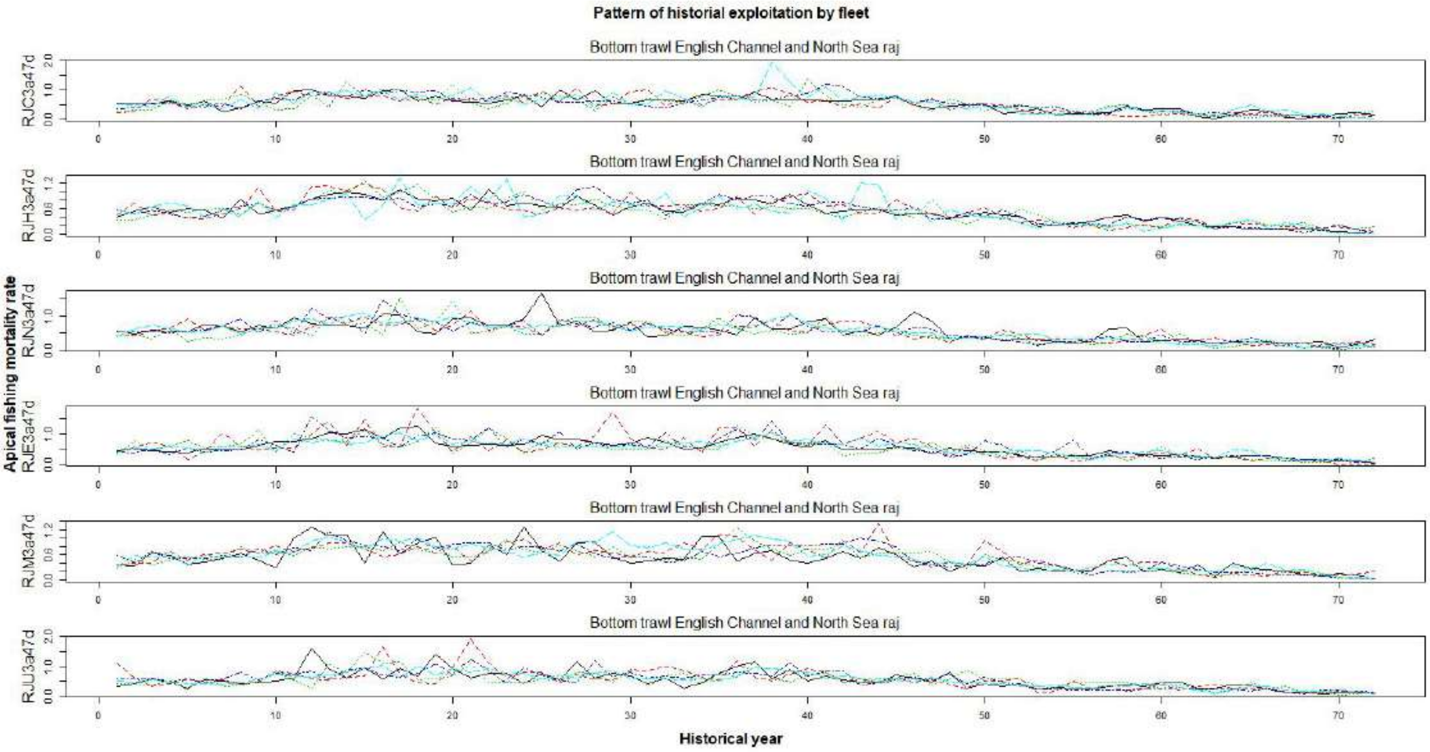

Figure 2 Top: Operating model fishing mortality simulation per species, RJC (*R. clavata*), RJH (*R. brachyura*), RJN (*L. naevus*), RJE (*R. microocellatta*), RJM (*R. montagui*), RJU (*R. undulata*).

Appendix 3 MSE scenarios

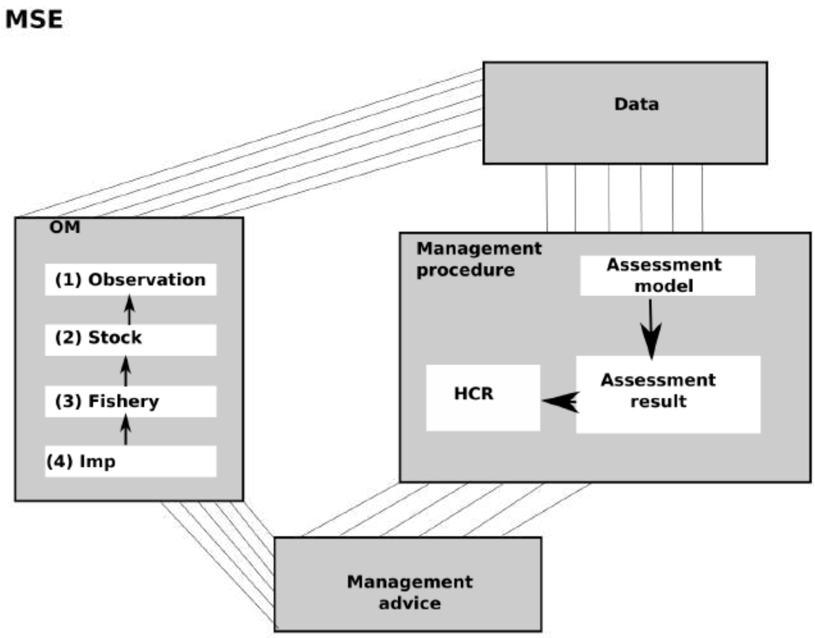

Figure 3 Species specific assessment and recommendation MSE 1

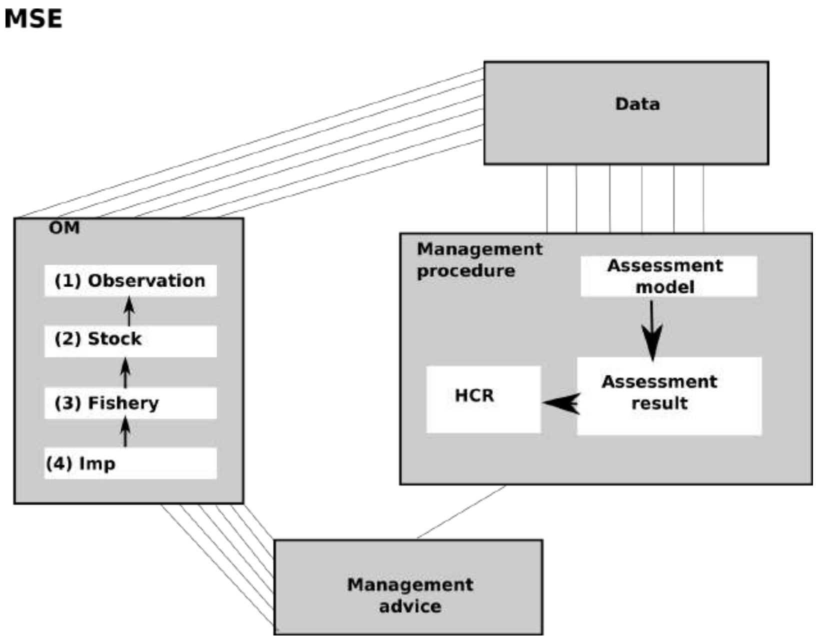

Figure 4 Species specific assessment and complex recommandation MSE 2

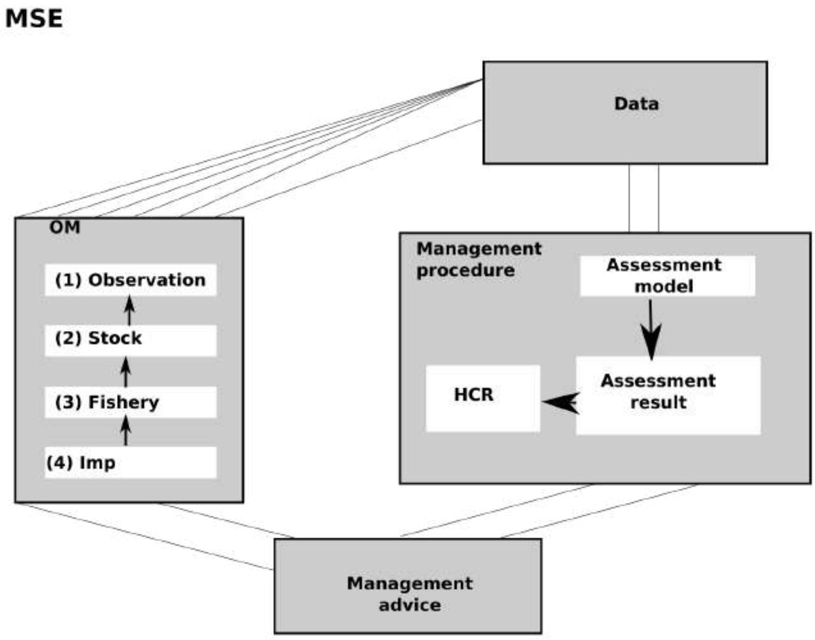

Figure 5 Species specific assessment and recommendation *R. clavata*, and complex assessment and recommendation other Rajidae species

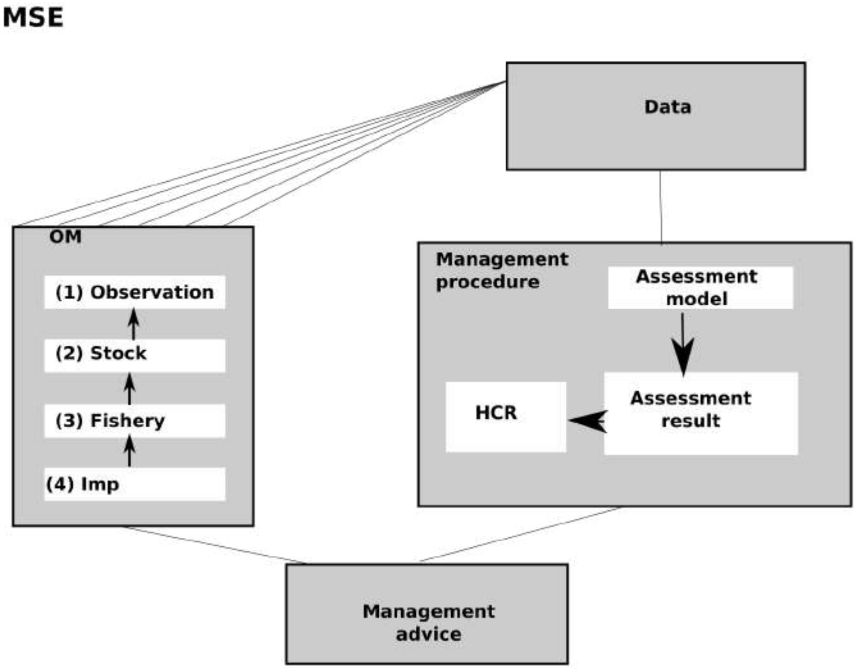

Figure 6 Complex assessment and recommendation all species