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UNCERTAINTY GRID FOR NORTH ATLANTIC ALBACORE MANAGEMENT STRATEGY EVALUATION: CONDITIONING OPERATING MODELS

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SUMMARY

Management Strategy Evaluation (MSE) requires characterizing the main sources of uncertainty inherent to fisheries. The unknowns that challenge the interpretation of fish stock assessments include gaps on biological processes and fishery dynamics. The first are often dealt by imposing ranges of input biological parameters to stock assessment models; and the second with assumptions over the available datasets. The uncertainties explored in the North Atlantic albacore MSE so far include the range of stock assessment scenarios tested in 2013 with the statistical, size-based, age structured model Multifan-CL. These explore the impacts of a range of data series combinations as the main source of uncertainty together with a natural mortality scenario. In this paper, we condition a grid of Operating Models by expanding the initial set of runs from 2013 using (a) alternatives for input biological parameters (natural mortality and steepness) and fishery dynamics (1% increase of catchability), and (b) projections using three scenarios for future recruitment. This work aims to expand the grid of OMs so that the tested HCRs are robust to a wider range of uncertainty.

RÉSUMÉ

L'évaluation de la stratégie de gestion (MSE) implique la caractérisation des principales sources d'incertitude inhérentes aux pêcheries. Les inconnues qui compliquent l'interprétation des évaluations des stocks de poissons incluent les lacunes des processus biologiques et des dynamiques des pêcheries. La première difficulté est souvent abordée en imposant des gammes de paramètres biologiques d'entrée dans les modèles d'évaluation des stocks tandis que la deuxième est résolue avec des postulats concernant les jeux de données disponibles. Les incertitudes explorées dans la MSE du germon de l'Atlantique Nord jusqu'à présent incluent la gamme de scénarios d'évaluation des stocks testés en 2013 avec le modèle Multifan-CL de type statistique, fondé sur les tailles et structuré par âge. Ceux-ci explorent les impacts d'une gamme de combinaisons de séries de données en tant que principale source d'incertitude ainsi qu'un scénario de mortalité naturelle. Ce document fait état du conditionnement d'une gamme de modèles opérationnels réalisé en élargissant le jeu initial de scénarios de 2013 au moyen de (a) alternatives aux paramètres biologiques d'entrée (mortalité naturelle et pente « steepness ») et aux dynamiques des pêcheries (augmentation de 1% de la capturabilité) et (b) projections réalisées au moyen de trois scénarios de recrutement futur. Le présent travail vise à élargir la gamme des modèles opérationnels de manière à ce que les HCR testées résistent à une plus grande gamme d'incertitudes.

RESUMEN

La evaluación de estrategias de ordenación (MSE) requiere la caracterización de las principales fuentes de incertidumbre inherentes a las pesquerías. Los elementos desconocidos que plantean un reto a la interpretación de las evaluaciones de stocks de peces incluyen lagunas relacionadas con los procesos biológicos y la dinámica de las pesquerías. Las primeras suelen abordarse mediante la imposición de gamas de parámetros biológicos de entrada en los modelos de evaluación de stock y la segunda con supuestos sobre los conjuntos de datos disponibles. Las

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incertidumbres exploradas en la MSE de atún blanco del Atlántico norte hasta la fecha incluyen la gama de escenarios de evaluación de stock probados en 2013 con el modelo estadístico estructurado por edad y basado en la talla Multifan-CL. Dichos escenarios exploran los impactos de una gama de combinaciones de series de datos como la principal fuente de incertidumbre junto con un escenario de mortalidad natural. En este documento, se condiciona una gama de modelos operativos expandiendo el conjunto de ensayos inicial de 2013 utilizando a) alternativas para los parámetros biológicos de entrada (mortalidad natural e inclinación) y dinámica de la pesquería (incremento del 1% en la capturabilidad), y b) proyecciones que utilizan tres escenarios para el reclutamiento futuro. El objetivo de este trabajo es expandir la gama de OM de tal modo que las HCR probadas sean robustas frente a un mayor grado de incertidumbre.

KEYWORDS

Tuna fisheries, Stock Assessment, Fishery Management, Quota Regulations, Resource Conservation, Harvest Control Rules, Management Strategy Evaluation, North Atlantic albacore, Operating Models

1. Introduction

Management Strategy Evaluation (MSE) is used to evaluate the impacts of the uncertainties inherent to fisheries (Punt et al., 2014). Conducting an MSE requires following a series of basic steps, which among others include (from Punt et al., 2014): (a) identifying a range of uncertainties related to biology, the environment, the fishery and the management system, to which a management strategy should be robust; (b) developing a set or grid of models which provide mathematical representation of the plausible dynamics of the fishery system (operating models, OM); and (c) fitting or conditioning the OMs and quantifying the impact of the uncertainties considered.

The foundational objective of the International Commission for the Conservation of Atlantic Tunas (ICCAT) is to maintain populations at levels that can permit the maximum sustainable yield (or above). For that, a series of recommendations have fostered the development of reference points (Rec. 11-04) and guidelines of decision making including Harvest Control Rules (Rec. 11-13 and Rec. 15-04). In 2016, the ability of a series of Harvest Control Rules to achieve management objectives for North Atlantic albacore was evaluated using MSE (Merino et al., 2016) and discussed in ICCAT's Panel 2 (ICCAT, 2016a). In 2016, the SCRS developed a schedule for the development of MSE and Harvest Control Rules, which included further evaluations of HCRs through MSE for North Atlantic albacore. In the workplan agreed by the SCRS for North Atlantic albacore as part of the multiyear Albacore Research program, priority was given to exploring broader scenarios for the OMs available in 2016 and to exploring the impact of recruitment regime shifts in the OMs (ICCAT, 2016b). Finally, in 2016, the Commission adopted a multiannual conservation and management program for North Atlantic albacore (Rec. 16-06). This Rec. requests that "*in 2017, the SCRS shall refine the testing of candidate reference points (e.g., $SSB_{THRESHOLD}$, SSB_{LIM} and F_{TARGET}) and associated harvest control rules (HCRs) that would support the management objective expressed in paragraph 2 above. The SCRS shall also provide statistics to support decision-making in accordance with the performance indicators in Annex 2. The result of the analyses described in paragraph 12 will be discussed in a dialogue between scientists and managers to be organised in 2017, either during a meeting of the SWGSM or as an inter-sessional meeting of Panel 2. Based on the SCRS inputs and advice provided pursuant to paragraph 12 above and the dialogue process indicated in paragraph 13, the Commission shall then endeavor in 2017 to adopt HCRs for the North Atlantic albacore, including pre-agreed management actions to be taken under various stock conditions*" (ICCAT, 2016c).

In this paper we have increased the number of OMs upon which evaluate the effectiveness of Harvest Control Rules for North Atlantic albacore. The new grid has been built upon the 2013 Multifan-CL scenario runs (ICCAT, 2013; Kell *et al*., 2017; Merino *et al*., 2016). Multifan-CL is a computer program that implements a statistical, size-based, age-structured, and spatial-structured model for use in fisheries stock assessment (Kleiber *et al*., 2012). The program is used routinely for tuna stock assessments by the Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC) in the western and central Pacific Ocean (WCPO) and both the Indian Ocean Tuna Commission (IOTC) and ICCAT have used this model for stock assessment. The model is fit to time series of catch and size composition data from either one or many fishing fleets. Size composition data may be in the form of either length or weight-frequency data, or both. The model may also be fit simultaneously to tagging data, if available.

The scenarios run in the 2013 assessment of North Atlantic albacore include a base case and alternate runs with a series of specific changes to include/exclude certain sources of data. The list of runs also includes one with an age-specific natural mortality vector. From the list of 10 runs from the 2013 assessment, we reproduced each run for higher and lower natural mortality values, obtaining a total of 30 scenarios. For each, we also developed a dynamic catchability scenario (mimicking an effort creep through time). In 2013, the steepness of the stock recruitment relation was estimated through a weak prior. Here, we created additional scenarios by imposing strict priors of steepness at a range of values (0.7, 0.8 and 0.9). The combination of the initial 10 runs with two additional natural mortalities, a dynamic catchability and three additional steepness scenarios results in a grid of 240 runs, which will be explained in detail in the next sections.

The OMs are conditioned from the output of the 240 Multifan-CL model runs. The overall selectivity, age-specific natural mortality, stock recruitment relationship, maturity and growth are taken directly from the Multifan-CL output files. The resulting OMs are projected forward to 2014, which was the last year of the data series' used in the 2016 assessment of this stock (ICCAT, 2016d). During the following sections we explore how the hypotheses considered when building the grid may impact the stock status, fishery indicators and reference points of North Atlantic albacore. Finally, we project forward each of the OMs with their estimated fishing mortality at MSY under three assumptions on the recruitment regime (current and ± 20% change).

2. Material and methods

2.1. Multifan-CL runs

The Multifan-CL scenarios for the 2013 scenarios are run through a series of files:

1) *mfcl.exe:* The executable file.
2) *albN.ini:* Information on biological characteristics of the fish.
3) *albN.frq:* Catch, effort and size data.
4) *doitallN.alb*: Batch execution file.
5) *albN.tag*: Tag release information (if available).

The starting point for the new grid was the 10 scenarios run with Multifan-CL in the 2013 stock assessment (ICCAT, 2013) (**Table 1**). In brief, the common features of the scenarios are (Merino *et al*., 2013; Kell *et al*., 2017):

- Single region,
- Catch data from 1930 to 2011 and size frequency from 1959 to 2011,
- 12 separate fisheries (with specific selectivity's),
- Beverton-Holt recruitment model following a weak relationship,
- Length-at-age assumed to be normally distributed for each age class with mean lengths at age following a von Bertalanffy growth curve,
- Time series of catchability for the Spanish bait boat and the Japanese longline fleets,
- Constant natural mortality at M=0.3,
- Maturity vector with 50% of mature at age-class 5 and 100% at age-class 6 onwards,
- China Taipei longline size frequency data not included,
- Japanese longline catch per unit of effort down-weighted.

a) Natural mortality: From the initial list (Table 1), the impact of the input natural mortality values was explored by reproducing the same scenarios with constant natural mortality of M=0.2 and M=0.4, plus the age-specific natural mortality vector of scenario Alt5 multiplied by 0.2/03 and by 0.4/0.3. This was done by modifying line 11 in the *albN.ini* file:

```
# natural mortality
0.3
```

For the scenarios derived from *Alt5*, the following age pars needed to be modified too:

```
# age_pars m=0.3 [10 sets of age-specific parameters for each age class] Includes fixed M not growth
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
-0.614336 -0.877070019 -1.046969056 -1.167962367 -1.255266099 -1.241328591 -1.158362293 -
1.072944542 -0.975510092 -0.867500568 -0.74865989 -0.610645959 -0.610645959 -0.610645959 -
0.610645959
```

The 15 mortality values for each of the 15 age classes are introduced in their log form in the age-pars in line 19 of the file. For example, for age-class 0, the value -0.614336 represents a value of $M_0=0.541$.

b) *Dynamic catchability:* A 1% increase in catchability was considered for all fisheries since 1980. Starting from line 44, the *albN.frq* files supply monthly data per fishery and age of fish. The sixth number of each line after line 44 corresponds to fishing effort, which is modified with equation (eq. 1):

```
# Year     Month     Week     Fishery     Catch(t)     Effort     Length_sample [30 32 34 36 ….
```

(eq. 1) $Effort_{t,dynq} = Effort_t \text{ x } 1.01^{year-\tau}$; τ being *max(1980, initial year of the series)*

c) *Steepness:* It is defined as the ratio of the equilibrium recruitment produced by 20% SSB_0 and the equilibrium recruitment at SSB_0. In 2013, the prior used corresponds to a mode of 0.75 and a standard deviation of 0.15, which is considered a weak prior. Steepness priors are introduced through age flags 153 and 154 in phase 7 of the *doitall_mod.alb* file, in this case with values of 35 and 21 (Merino et al., 2013):

```
2 153 35 #
2 154 21 #
```

We have added three more steepness prior alternatives (modes of 0.7, 0.8 and 0.9), all with standard deviations of 0.05, which can be considered stricter than the 2013 prior. To do so, the 153 and 154 age-flags need to be replaced with the numbers Table 2.

To sum up, 240 scenarios were available to run in Multifan-CL, which were named with a string containing the name of the original scenario, followed by a mortality identifier (*M02*, *M03*, *M04*), a steepness identifier (*h6*, *h7*, *h8*, *h9*; *h6* being the weak prior of 0.75 and the following the strong priors of *0.7*, *0.8*, *0.9*), and a dynamic catchability identifier (*q0* and *q1*, being the latest the dynamic q). For example, the scenario *Alt4_M02_h8_q1* is based on the original *Alt4* but with a natural mortality value of 0.2, a strong steepness prior of 0.8 and effort data modified to simulate the impacts of a 1% increase in catchability since 1980.

2.2. Conditioning of the Operating Models

The outputs of the Multifan-CL runs were used to condition 240 OMs. The results of the stock assessments are contained in the files *07.par* and *plot-07.par* for each scenario. The OMs were conditioned using libraries from the FLR-project (www.flr-project.org). The libraries used are *FLCore*, *FLash* and *FLBRP*, all available from the FLR repository (http://flr-project.org/R). In particular, the function *readMFCL* applied to the two results files creates an FLR object of the type *FLStock,* containing the features of the stock as estimated from Multifan-CL. The new object is composed by a single fishery and includes parameters (selectivity, growth, natural mortality, stock-recruitment and maturity), time series of catch and biomass (in total and by age) and harvest time series, among other information. Additional FLR functions were used to estimate reference points and equilibrium curves. Finally, the OM were projected forward to 2014 with total catch information from 2012-2014.

Regime shifts projections:

Changes in recruitment can also be part of the Operating Models and hypotheses to which harvest strategies need to be robust in a MSE framework (Merino et al., 2016). As a preliminary exploration of what an overall increase of recruitment can produce on this fishery we projected forward the grid of scenarios under F_{MSY} and three regimes for future recruitment: 1) Future recruitment will follow the stock-recruitment relationship as estimated by Multifan-CL, 2) recruitment will follow the same relationship but the estimates will be increased in a 20% and, 3) recruitment will follow the same relationship but the estimates will be reduced in a 20%.

3. Results

When fitting a model with multiple parameters it is possible to initially fix some parameters during the first optimization (of some other parameters), the fixed parameters are then being estimated in later phases. This helps in fitting since the most influential parameters can be addressed first. **Figures 1 and Figure 2** show the values of the objective function and the number of parameters estimated for each scenario and phase (see also **Table A1**). The scenarios in these figures are colored relative to their original scenario from 2013 runs. Overall, all the runs fit a major part of parameters in the first phase. The biggest change in the likelihoods is seen between phase 1 and 2 when selectivity is estimated. Note that scenario Alt5 has 8 phases.

The impact of each of the components of the grid proposed here are shown in **Figures 3 and 4. Figure 3** shows the ranges of equilibrium management indicators and reference points produced for each of the components on the 2013 base case scenario. **Figures 3, 4 and 6** show the impact of variations on natural mortality, steepness and catchability on: (i) equilibrium spawning stock biomass (ssb) vs fishing mortality, (ii) equilibrium recruitment vs ssb, (iii) equilibrium yield vs fishing mortality, and (iv) equilibrium yield vs ssb. The 2013 base case scenario assumes a production function skewed to the left with an estimated MSY slightly above 30 th tons. The greatest impacts on the 2013 base case are produced by natural mortality. In particular, increasing natural mortality requires that the model compensates the consequent loss of biomass by increasing recruitment. In contrast, lower M produces a lower estimate of recruitment for the same amount of ssb. Another relation that changes notable with M is the equilibrium yield vs ssb. The estimated unexploited biomass and the biomass at MSY are significantly reduced for higher M. In contrast, the estimated MSY is not modified. With regards to the steepness priors, the impact is noted in the estimated stock recruitment relation and the yield vs F curve. Higher steepness produces lower recruitment at high ssb but higher recruitment at low levels of ssb. As expected, the OM conditioned with the highest steepness scenarios will be more resilient when the stock is severely overexploited. With regards to the assumption of dynamic catchability, it does not produce notable changes on the estimated equilibria and reference points of the fishery.

In 2013, the range of modelling specifications considered produced alternative estimations of albacore's population dynamics (**Figure 4**). Looking at the 2013 scenarios only, the largest differences in production functions are between scenarios Alt2 and Alt8, which included the lowest estimated recruits-per-spawner and estimated MSY for Alt2 and the highest for Alt8. Alt8 was originally designed to explore if combining CPUE and catch data in numbers and in weight into Multifan-CL could produce appreciable impacts on the overall results of the assessment. Scenario Alt2 excluded data prior to 1950 and results suggest that the previous period may have been less productive than the more recent. Alt5 scenario assumes higher natural mortality for all ages than its corresponding scenario with M constant for all ages (e.g M03, see **Figure 5**). Therefore, the model requires higher recruits to explain the available data. Scenario Alt3 also estimates a fish stock with lower productivity than average. This scenario down-weighs all the size frequency information.

The effect of each of the biological parameters explored here upon the initial scenarios also suggests that the assumptions on natural mortality produce the major effect on fisheries' productivity. As said earlier, increasing the input natural mortality parameter produces higher recruits-per-spawner in order to sustain the observed catch levels. The impact of the initial priors on steepness produces relevant changes for the response of severely overexploited stocks. Also, there is no appreciable pattern on the dynamic catchability assumption on fish stocks productivity across 2013 scenarios.

Similar results are seen in **Figure 6,** where the impact of each biological parameter is explored for all the grid of scenarios. Again, a clear relation is seen between the fixed natural mortality level, recruitment per spawner and production functions. Higher M produce estimates of lower MSY and higher recruit-per-spawner.

Figure 7 explores the impact of the biological parameters on reference points and stock status in 2015. The relation between M, steepness, virgin biomass and MSY is clearly appreciated. Again, higher M produces estimates of lower B_0 and MSY. The patterns observed for the relation between M, B_{MSY}, F_{MSY} and relative B and F in 2015 are also noted but also depend on the catchability assumptions. Figure 8 shows these with a different color scale, where the impact of the assumption on dynamic catchability is more clearly appreciated. Assuming the dynamic q produces higher estimates of B_{MSY} and lower of F_{MSY}. However, the impact of the dynamic q is less than M in some cases. For example, using 0.2 as M scenario can produce wider differences than the dynamic q alone (Alt 7). However, for equal M and h scenarios, the assumption of dynamic q produces higher B_{MSY} and lower F_{MSY}. With regards to stock status, lower natural mortality produces estimates of lower relative biomass and higher relative fishing mortality in 2015 (**Figure 6**). In addition, dynamic q produces more pessimistic estimates of stock status. The impact of steepness priors is also appreciated in reference points and stock status: The highest levels of steepness correspond to lower estimates of B_0, B_{MSY} and relative F; and higher estimates of F_{MSY} and relative biomass.

Figure 9 shows the dependency of the estimated aggregate selectivity with biological parameters on the 2013 set of scenarios. This figure shows that in general, increasing the fixed natural mortality produces a reduction on the overall selectivity in the early ages and a minor increase in older age classes. However, scenario Alt3 shows an inverse tendency, increasing M produce estimates of higher selectivity at early ages and higher for older. As said earlier, Alt3 is the scenario with all size-frequency data downweighted. With regards to steepness and assumption on catchability, this figure shows that they do not produce effects on the estimated selectivity except for scenario Alt3, where the assumption of increased catchability produces a reduction of the estimated selectivity for the early ages and increased selectivity for the older.

The estimated time series of recruitment (Rec), spawning stock biomass (SSB), catch and harvest or fishing mortality rates are shown in **Figure 10**. This figure shows the trajectory of the North Atlantic albacore as estimated with the alternative modelling options described in the uncertainty grid. Each of the scenarios has its own residuals of fit to the available and estimated data series. For example, **Figure 11** explores the residuals of the scenario used in 2013 as a base case (*Base_M03_h6_q0*). Among other information, this figure shows a potential sinusoidal pattern on the temporal estimate of residuals. Before 1950 the residuals are negative while since then start to increase until a peak in the late 1960s, where residuals start to decrease until now, when they are negative again. This result may suggest that this stock has gone through different phases of recruitment productivity, i.e. periods where the stock has been able to produce more recruits with the same amount of ssb.

As a preliminary exploration of what an overall increase on recruitment can produce on this fishery we projected forward the grid of scenarios under three regimes for future recruitment. **Figure 12** shows the expected increase/decrease in fishery indicators driven by changes on current recruitment regime.

4. Discussion

In order to develop MSE, it is necessary getting agreement on the scenarios considered as Operating Models (tRFMO-MSE, 2016). A grid of OM scenarios (i.e. a design based on factors and levels) dealing with parameter and structural uncertainty has primarily been the basis of most development work so far across fisheries. Following SCRS workplan for albacore (ICCAT, 2016b), this paper shows how the OMs for the North Atlantic albacore MSE have been built. This document aims at elucidating the impact of the range of uncertainties covered by the OMs and at adding transparency and credibility to the North Atlantic albacore MSE. Our results show that fishery indicators' trends are similar in all runs (**Figure 10**), but also confirm that estimates of stock status, equilibrium curves and reference points are highly dependent upon the assumed biology and fishery dynamics (Kell *et al.*, 2013).

In 2013, a list of scenarios was developed to explore the impact of including/excluding certain parts of the available information. Overall, most of the scenarios produced similar estimates of productivity except the scenario with the age structured natural mortality, the scenario starting in 1950 and the combination of data in weights and number. From the 2013 list, a grid of scenarios was developed exploring the combined impacts of alternatives of input natural mortality, steepness priors and catchability.

Natural mortality is the most relevant parameter of the grid. Overall, the fixed natural mortality produces changes on the estimates of the reference points, selectivity and stock status. In order to explain the catch information, the Multifan-CL compensates the losses of catch and natural mortality with recruitment. Higher levels of M produce estimates of higher recruitment for the same amount of SSB. Virgin biomass and estimated MSY are greater for lower levels of M. Stock status, B_{MSY} and F_{MSY} are also related to M but the wide range of estimates is explained by catchability assumptions.

Changes on steepness priors have also produced changes on the indicators explored, in particular on the resilience of the stock to severe overexploitation states. **Figure 13** shows a series of histograms produced with the mode and standard deviations for each scenario in gray and the estimated values of steepness (in colors). The estimated values tend to be in the upper region of the priors.

Stock status, F_{MSY} and B_{MSY} are also dependent upon catchability assumptions. The assumption of increased catchability since 1980 affects the estimation of current stock status (higher fishing mortality and lower biomass). This assumption has generally been used to reflect the technological improvements of the fleets. This is particularly evident for purse seine gears targeting tropical tuna, which in the 1980s decade started using artificial fish aggregating devices and high-tech monitoring and observation tools, reaching catchability increases of up to 3% per year (Lopez *et al.*, 2015; Lopez *et al.*, 2014). For longline fleets fishing power has increased more moderately than for purse seiners (Hoyle and Okamoto, 2011). Despite the increasing recent contribution from pelagic trawlers, North Atlantic albacore is mostly fished by artisanal fleets (baitboat and trolling) and only partially by longline fleets that capture albacore as by-catch. Traditional gears have not experienced the same level of catchability increase (at least due to improved technology of the fishing gear). In addition, for this stock, due to its spatial distribution during the fishing season, it is more likely that catchability has decreased due to reduced availability in the recent period rather than increased due to improvements in technology. However, the dynamic catchability scenarios reflect the possibility that effective effort has yet increased at a 1% rate, on top of what is already standardized for.

Following the tRFMO MSE working group (2016), scenarios dealing with sampling and time series approaches that account for non-stationarity of ecological processes should be examined also. Here, we have explored the direct impact of increasing and decreasing average recruitment due to regime shifts. The runs shown are very preliminary but we think that they should contribute to the MSE development for North Atlantic albacore in the future.

For the North Atlantic albacore MSE to be developed, the grid of OMs needs to be agreed. Our proposed grid expands the previous list of OMs (**Table 3**), and now includes options with respect to the information available (2013 scenarios: catch, CPUE, size frequency data), biological parameters (natural mortality and steepness) and fishery dynamics (technological improvements and regime shifts) and are similar to the MSE developments in other tRFMOs (Bentley and Adam, 2016; Kolody and Jumppanen, 2016; Mosqueira, 2016; tRFMO, 2016). The plausibility of the hypotheses considered in this grid can be further evaluated before MP evaluations, in order to select Reference Case scenarios, robustness trials or simply to discard some of them. Also, additional scenarios could have been tested (Kell *et al*., 2013) but so far we have considered a range of uncertainties that are disseminated through the models and produce alternative views of North Atlantic albacore’s dynamics, productivity and current state.

References

Bentley, N. and S. Adam. 2016. Management strategy evaluation for the Indian Ocean skipjack tuna fishery. IOTC/WPM07/015.

Hoyle, S.D.,Okamoto, H. 2011. Analyses of Japanese longline operational catch and effort for bigeye and yellowfin tuna in the Western Central Pacific Ocean. SC7/2011/SA IP-01

ICCAT. 2011. Recommendation by ICCAT on the principles of decision making for ICCAT conservation and management measures (Rec. 11-13).

ICCAT. 2016a. Report of the intersessional meeting of Panel 2. Sapporo-Japan.

ICCAT. 2016b. Report of the Standing Committee on Research and Statistics (SCRS), Madrid, Spain, 3 to 7 October 2016. 429 pp.

ICCAT. 2016c. Recommendation by ICCAT on a multi-annual conservation and management program for North Atlantic albacore (Rec. 16-06).

ICCAT. 2016d. Report of the 2016 ICCAT North and South Atlantic albacore stock assessment meeting, Madeira (Portugal) - April 28 to May 6, 2016.

ICCAT. 2015. Recommendation by ICCAT to establish harvest control rules for the North Atlantic albacore stock (Rec. 15-04).

ICCAT. 2013. Report of the 2013 ICCAT North and South Atlantic albacore stock assessment meeting, Sukarrieta (Spain), 114pp.

ICCAT. 2011. Supplemental recommendation by ICCAT concerning the North Atlantic albacore rebuilding program (Rec. 11-04).

Kell, L., Arrizabalaga, H., Merino, G., De Bruyn, P. 2017. Conditioning an Operating Model for North Atlantic albacore. Collect. Vol. Sci. Pap., ICCAT 73(4): 1296-1327.

Kell, L., Merino, G., de Bruyn,Ortiz de Urbina, J., Arrizabalaga, H., Santiago, J., Murua, H. 2013. An example of conditioning an Operating Model using Multifan-CL. ICCAT, SCRS/2013/34 Technical Paper.

Kleiber, P.,Hampton, J.,Davies, N.,Hoyle, S.,Fournier, D.A. 2012. MULTIFAN-CL User's Guide. 152 pp.

Kolody, D. and P. Jumppanen. 2016. IOTC yellowfin and bigeye tuna Management Strategy Evaluation: Phase 1 Technical Support. Project Final Report. IOTC/2016/032.

Lopez, J.,Fraile, I.,Murua, J.,Santiago, J.,Merino, G.,Murua, H. 2015. Technological and fisher's evolution on fishing tactics and strategies on FADs vs. non-associated fisheries. IOTC/2015/WPTT17.

Lopez, J.,Moreno, G.,Sancristobal, I.,Murua, J. 2014. Evolution and current state of the technology echo-sounder buoys used by Spanish tropical tuna purse seiners in the Atlantic, Indian and Pacific Oceans. Fisheries Research. 155:127-137.

Merino, G.,Arrizabalaga, H.,Murua, H.,Santiago, J.,Ortiz de Urbina, J.,Scott, G.P.,Kell, L. 2016. Evaluation of Harvest Control Rules for North Atlantic albacore through Management Strategy Evaluation. SCRS/2016/015.

Merino, G.,De Bruyn, P.,Kell, L.,Arrizabalaga, H. 2013. A preliminary stock assessment for Northern albacore using the fully integrated stock assessment model, Multifan-CL. SCRS/2013/58.

Mosqueira, I. Management Strategy Evaluation for the Indian Ocean Tuna Albacore stock. 2016. IOTC/2016/WPM07-08.

Punt, A.,Butterworth, D.D.S.,de Moor, C.L.,De Olveira, A.A.,Haddon, M. 2014. Management strategy evaluation: best practices. Fish and Fisheries.

tRFMO-MSE. 2016. Kobe MSE Working Group Kick off Meeting Report, Madrid, 1-3 Nov 2016.

Santiago, J.,Arrizabalaga, H. 2005. An integrated growth study for North Atlantic albacore (*Thunnus alalunga* Bonn. 1788). ICES Journal of Marine Science. 62:740-749.

Table 1. MFCL model runs and specifications (all alternate runs are the same as the base case run except for the changes specified).

Run	*Specifications*
Base	Model specifications provided in SCRS/2013/058
Alt1	Includes Chinese Taipei longline size frequency data and allows dome-shaped selectivity for this fleet
Alt2	Model starts in 1950
Alt3	All size frequency data down-weighted
Alt4	Japanese longline catch per unit of effort data no longer down-weighted
Alt5	Includes the Chen and Watanabe age-specific natural mortality vector (Santiago and Arrizabalaga, 2005)
Alt6	Excludes final 4 years of data (2008-2011)
Alt7	Includes equal weights for Japan and Chinese Taipei longline size frequency data and catch per unit of effort data
Alt8	Includes total catch in weight but effort calculated from CPUE in numbers
Tag	Includes tagging data for release events that occurred between 1988 and 1991 (*albN.tag*)

Table 2. Steepness priors explored and value of flags.

Steepness mode	St deviation	Age flag 153	Age flag 154
0.75	0.15	35	21
0.7	0.05	368	225
0.8	0.05	357	126
0.9	0.05	269	47

Table 3. MFCL options used on top of the 2013 list of scenario runs.

Added factors	*Natural Mortality*	*Steepness prior*	*Catchability dynamics*	*Recruitment regime*
Value	• 0.2 • 0.3 • 0.4	• 0.75 (sd=0.15) • 0.7 (sd=0.05) • 0.8 (sd=0.05) • 0.9 (sd=0.05)	• Constant • +1% (>1980)	• 0% • +20% • -20%

Figures

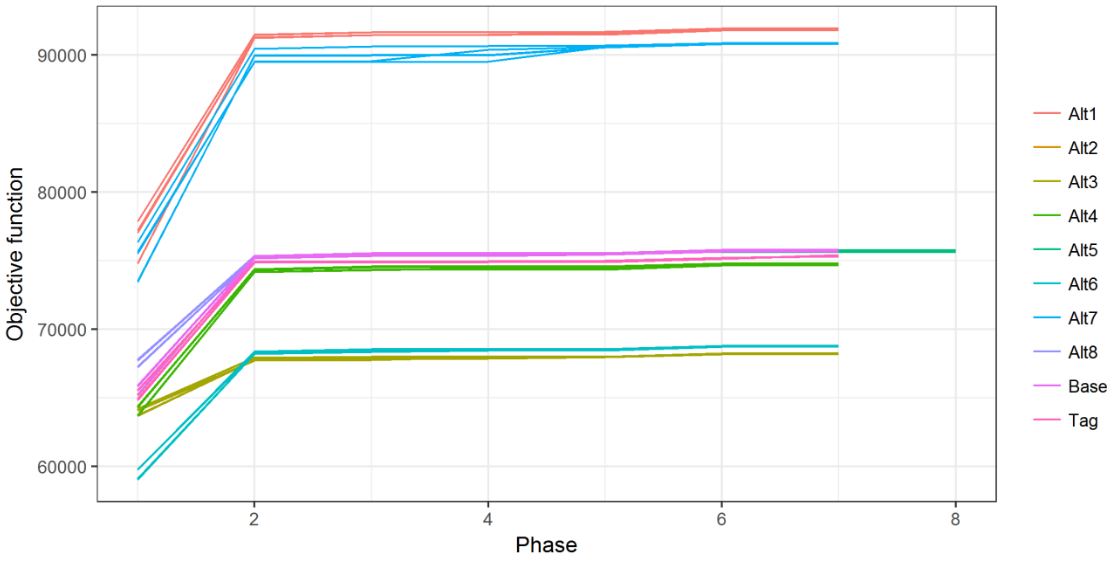

Figure 1. Objective function in the different phases of the fit to MFCL scenarios.

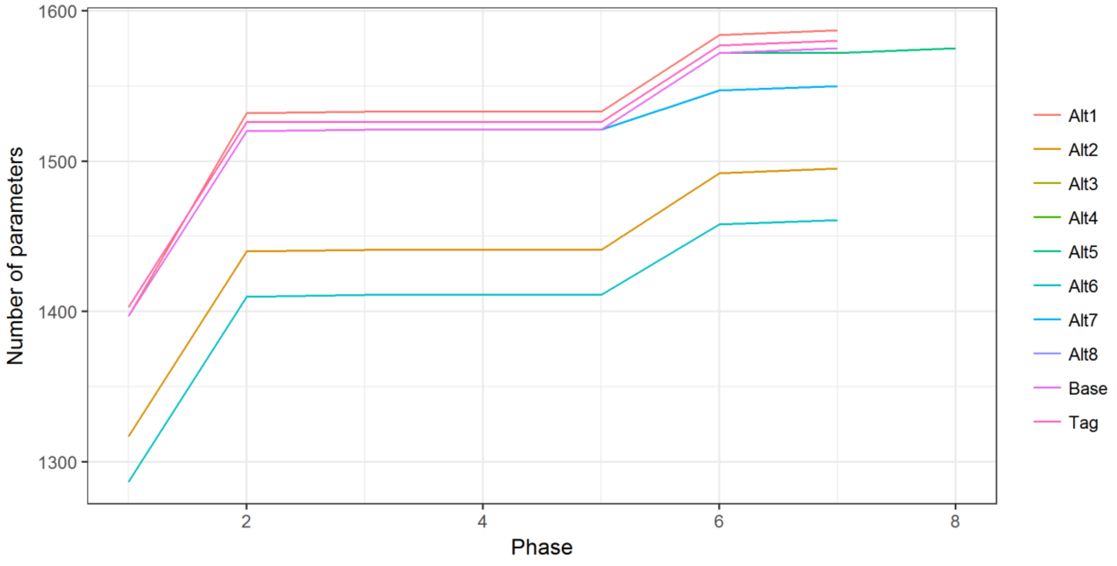

Figure 2. Number of parameters in the different phases of the fit to MFCL scenarios.

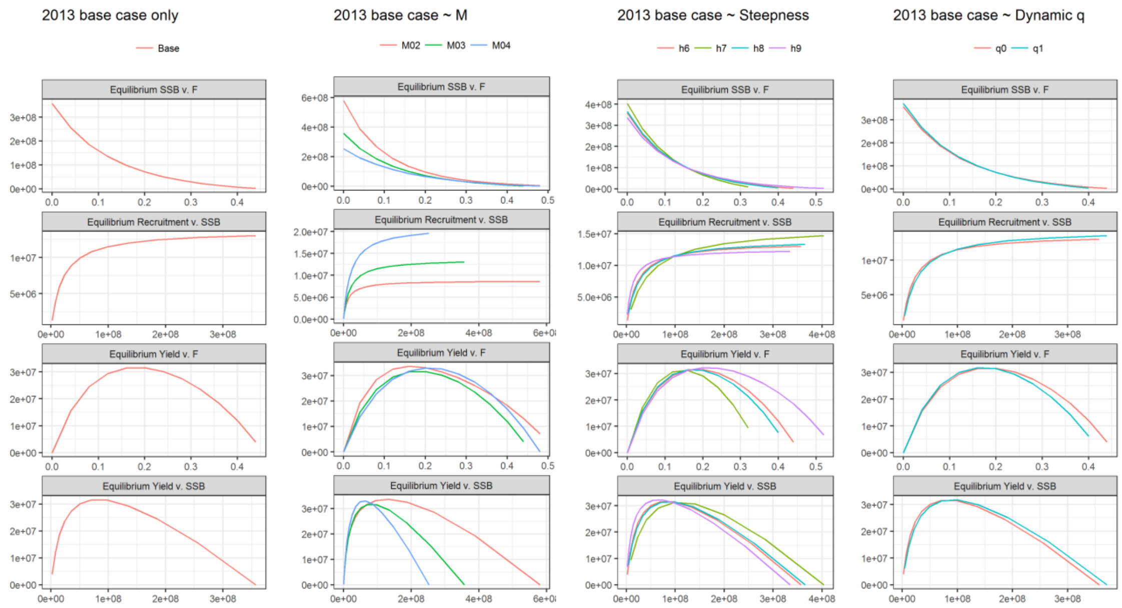

Figure 3. Impact of natural mortality, steepness and dynamic catchability on the MFCL Base Case scenario.

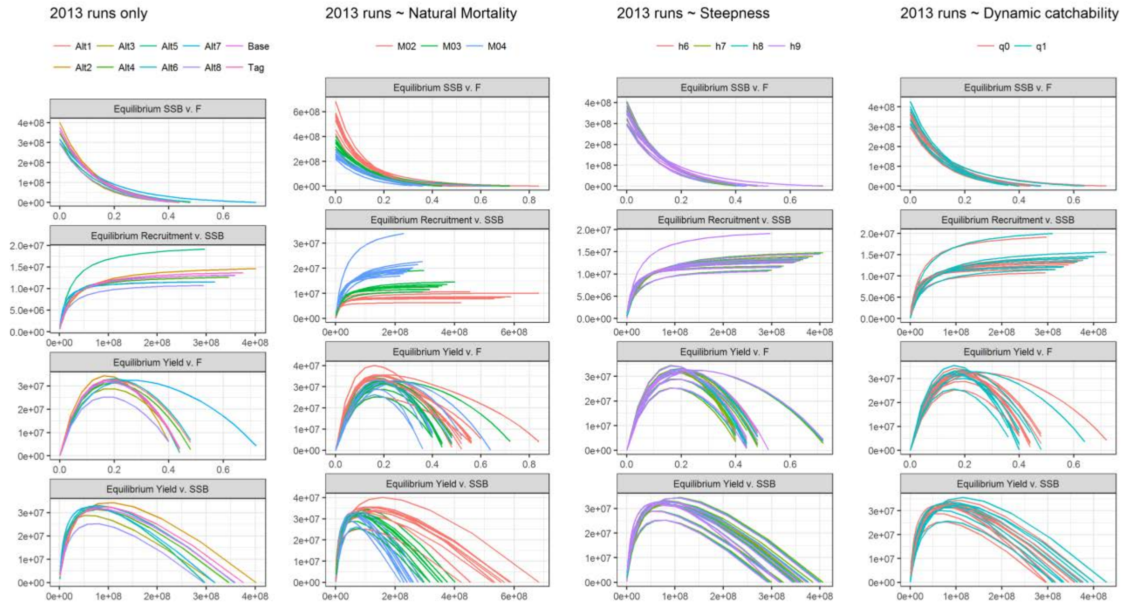

Figure 4. Impact of natural mortality, steepness and dynamic catchability on the MFCL scenarios considered in 2013.

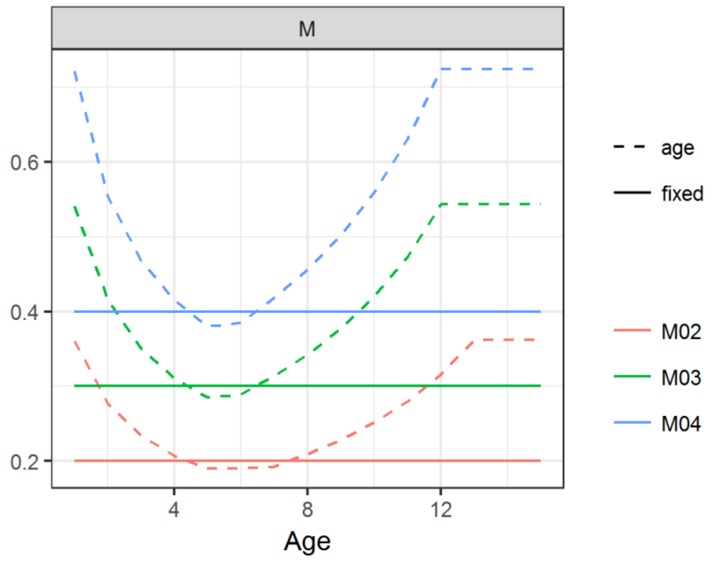

Figure 5. Natural mortality vectors considered in the grid of OMs.

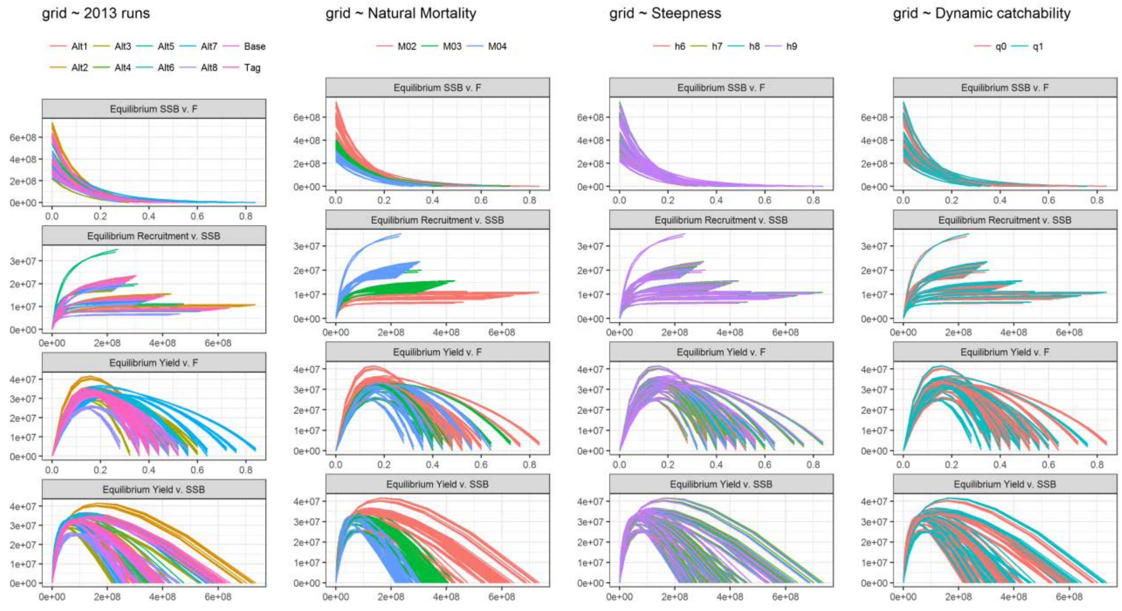

Figure 6. Impact of natural mortality, steepness and dynamic catchability on the grid of scenarios.

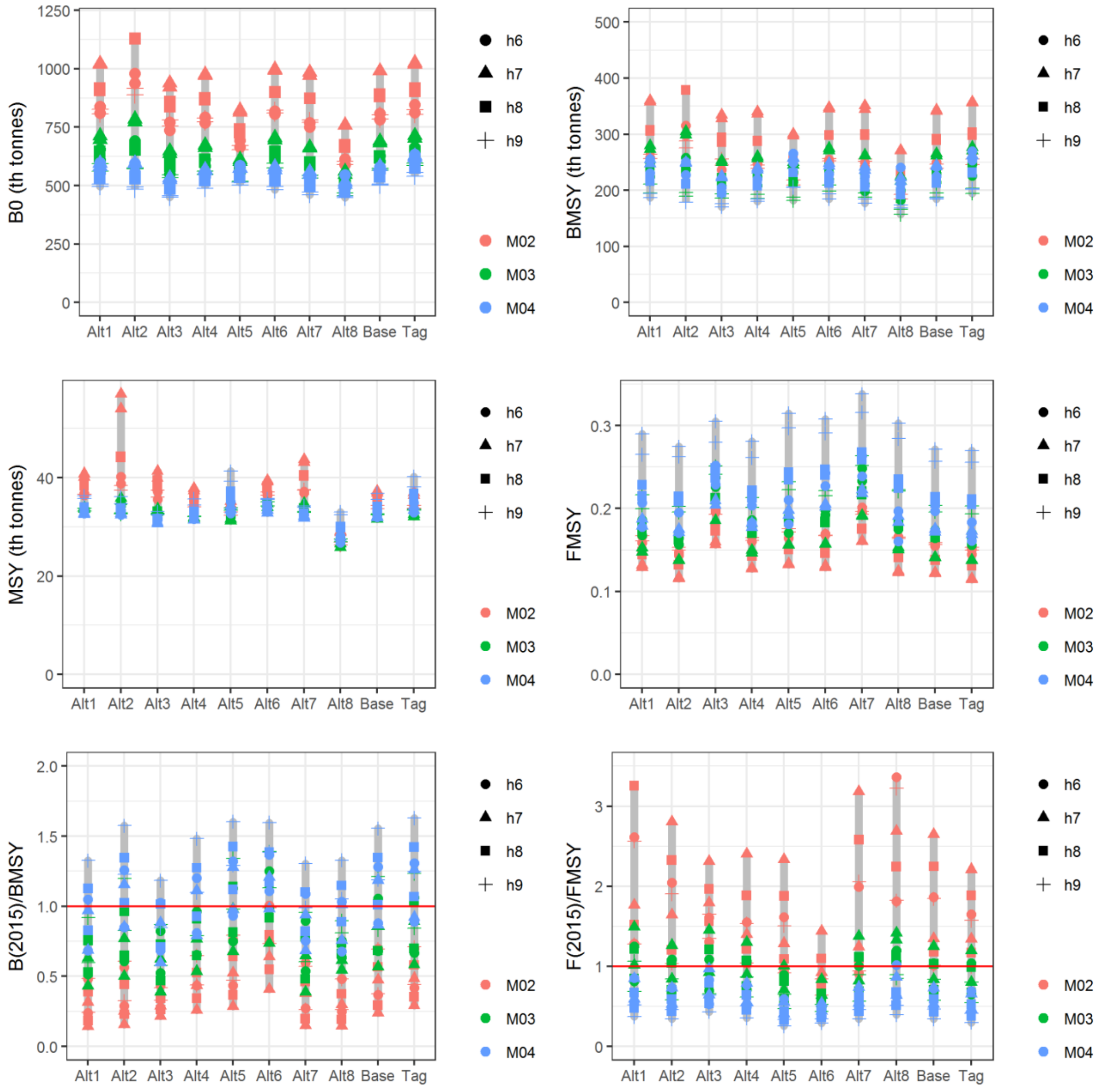

Figure 7. Reference points and current status estimated in the 240 OMs. The results are coloured to show the impact of alternative natural mortality values. Different shapes allow showing the impact of steepness.

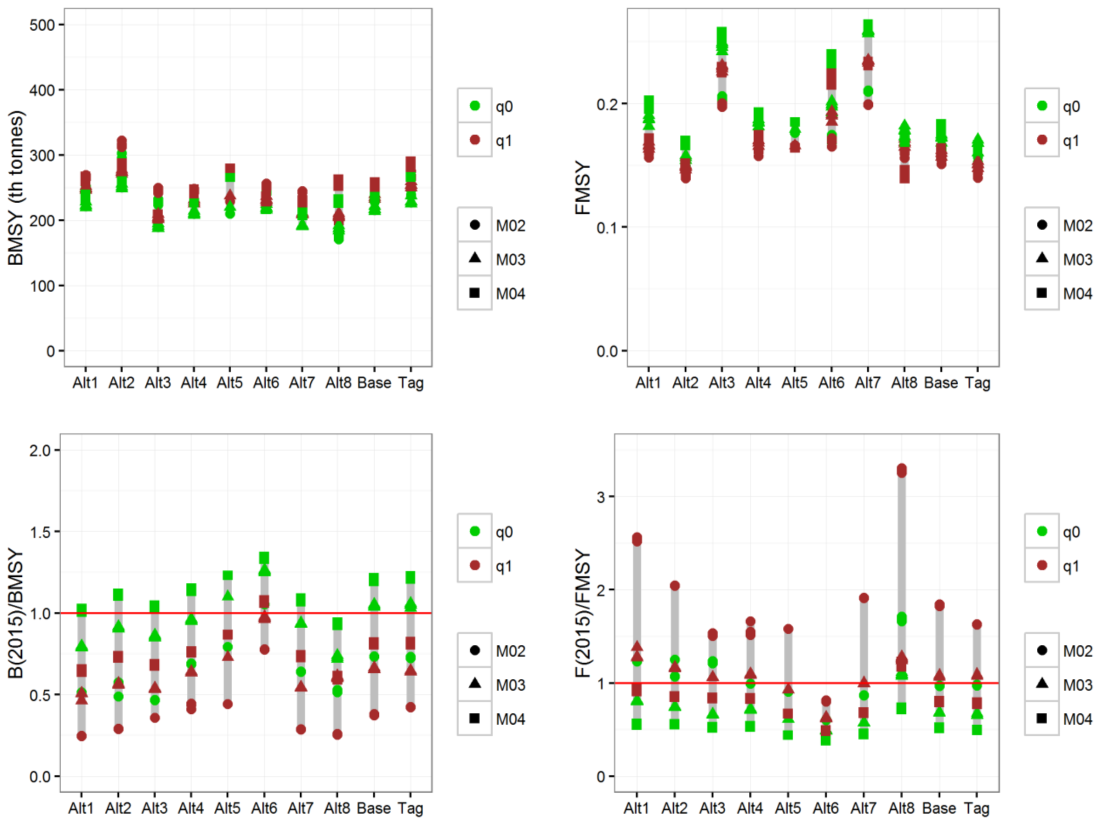

Figure 8. Reference points and current status estimated in the 240 OMs. The results are coloured to show the impact of dynamic catchability assumption. Different shapes allow showing the impact alternative natural mortality values.

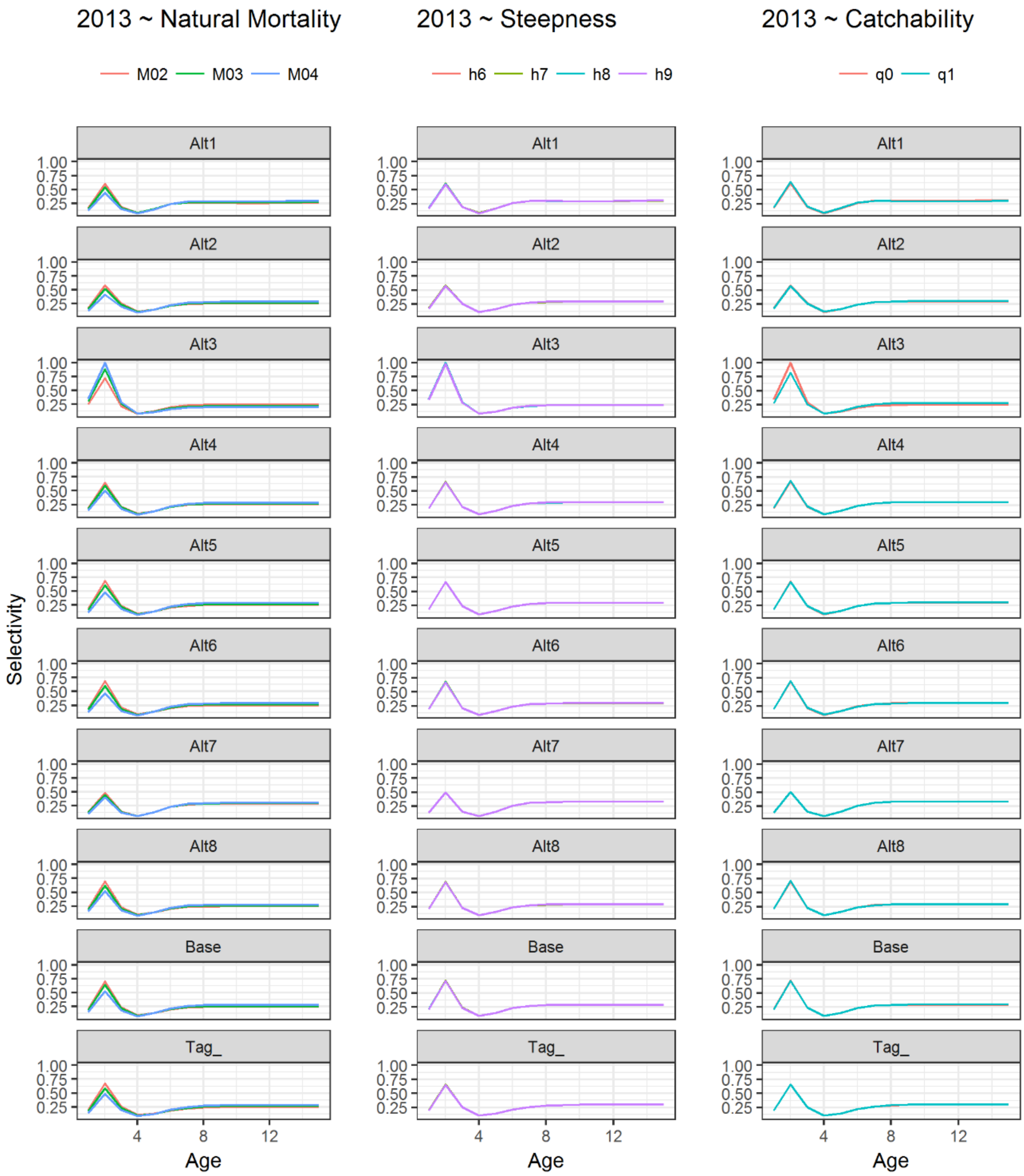

Figure 9. Aggregated selectivity.

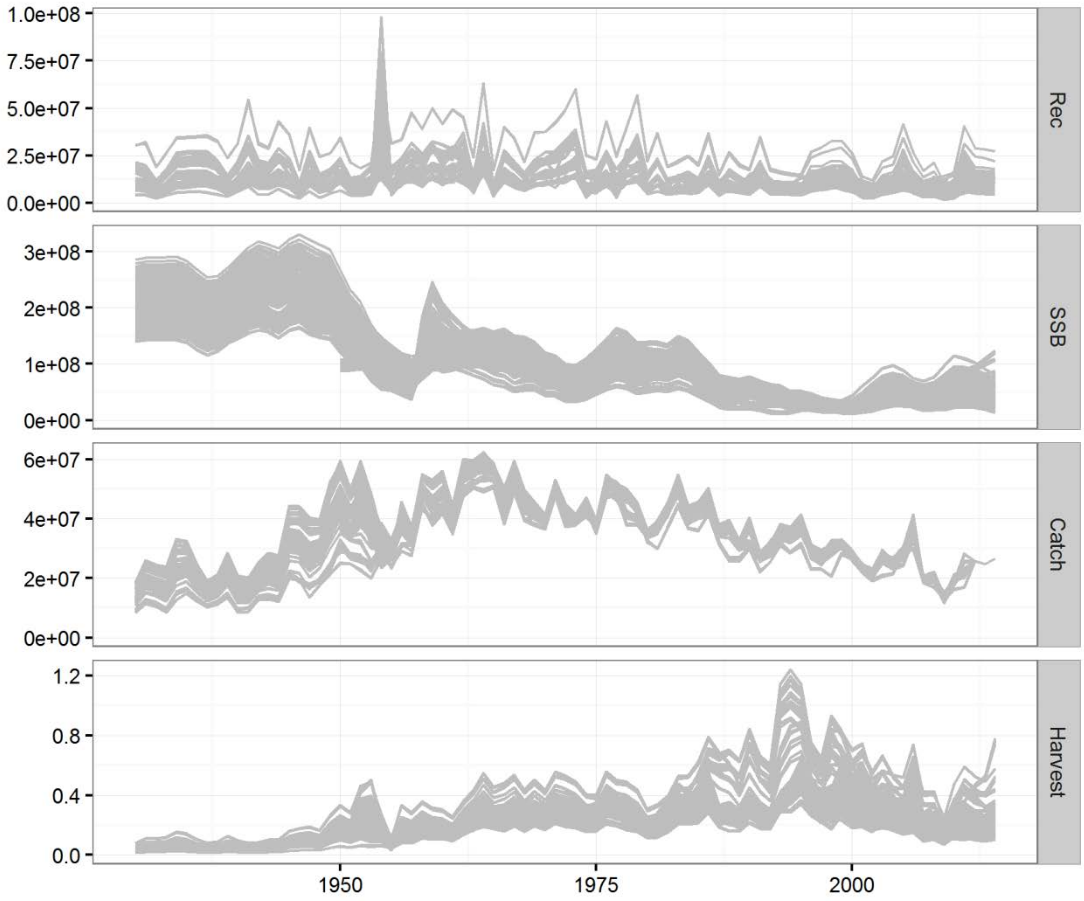

Figure 10. Time series of recruitment, spawning stock biomass, catch and fishing mortality rate for the 240 OMs.

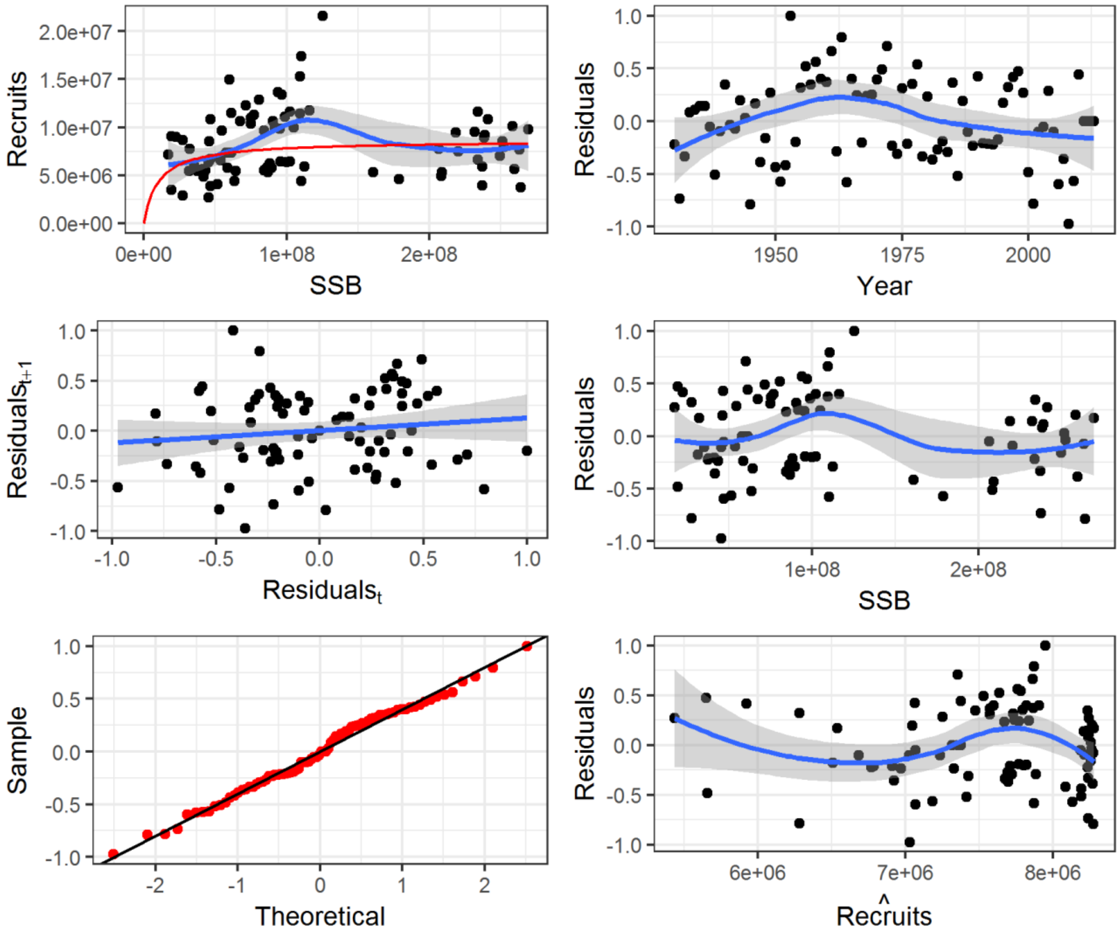

Figure 11. Residuals of the scenario used in 2013 as a base case (*Base_M03_h6_q0*).

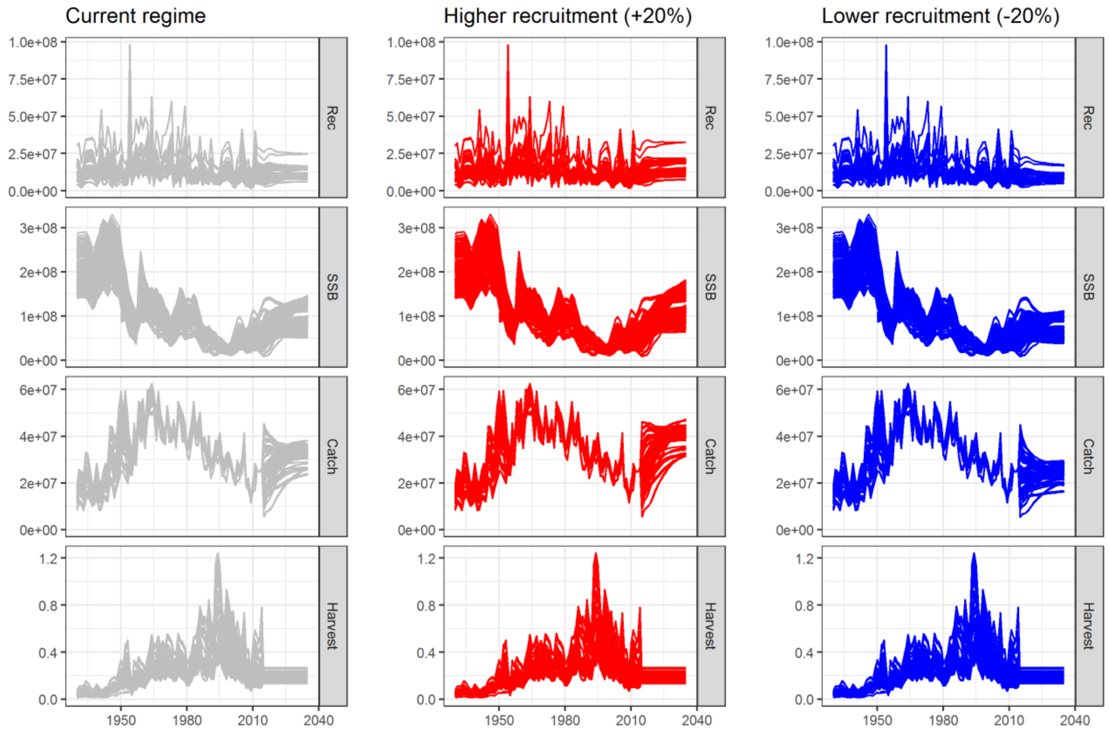

Figure 12. Projections of the 240 OMs with three recruitment regimes.

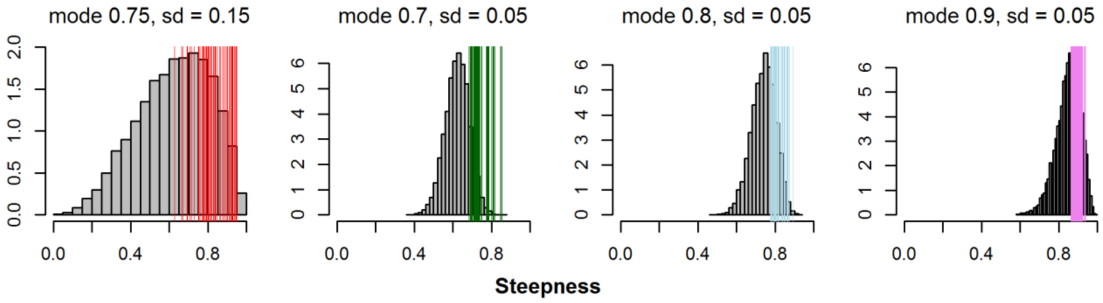

Figure13. Priors for steepness scenarios (gray) and estimated value (coloured).

Appendix

MFCL scenario	***Objective function***	***Number of parameters***	***Steepness***
Alt1_M02_h6_q0	91922.771	1587	0.9154
Alt1_M02_h6_q1	91944.3939	1587	0.9015
Alt1_M02_h7_q0	91918.2764	1587	0.8118
Alt1_M02_h7_q1	91940.5203	1587	0.8086
Alt1_M02_h8_q0	91922.4459	1587	0.8639
Alt1_M02_h8_q1	91944.4754	1587	0.8595
Alt1_M02_h9_q0	91924.4867	1587	0.9173
Alt1_M02_h9_q1	91946.1512	1587	0.908
Alt1_M03_h6_q0	91875.8081	1587	0.8271
Alt1_M03_h6_q1	91895.8618	1587	0.7889
Alt1_M03_h7_q0	91876.0166	1587	0.7375
Alt1_M03_h7_q1	91896.5012	1587	0.7303
Alt1_M03_h8_q0	91876.9895	1587	0.8108
Alt1_M03_h8_q1	91897.0733	1587	0.7979
Alt1_M03_h9_q0	91877.0145	1587	0.8883
Alt1_M03_h9_q1	91898.116	1587	0.8626
Alt1_M04_h6_q0	91831.8921	1587	0.7509
Alt1_M04_h6_q1	91849.3853	1587	0.692
Alt1_M04_h7_q0	91833.0135	1587	0.7069
Alt1_M04_h7_q1	91850.6814	1587	0.6944
Alt1_M04_h8_q0	91833.0239	1587	0.7936
Alt1_M04_h8_q1	91850.0931	1587	0.7766
Alt1_M04_h9_q0	91832.6733	1587	0.886
Alt1_M04_h9_q1	91849.0837	1587	0.8619
Alt2_M02_h6_q0	75775.5156	1495	0.8886
Alt2_M02_h6_q1	75801.2799	1495	0.8767
Alt2_M02_h7_q0	75775.82	1495	0.7725
Alt2_M02_h7_q1	75799.4037	1495	0.7784
Alt2_M02_h8_q0	75776.1413	1495	0.8372
Alt2_M02_h8_q1	75801.9737	1495	0.8384
Alt2_M02_h9_q0	75777.1461	1495	0.9058
Alt2_M02_h9_q1	75802.809	1495	0.8965
Alt2_M03_h6_q0	75729.1323	1495	0.8033
Alt2_M03_h6_q1	75751.4263	1495	0.776
Alt2_M03_h7_q0	75729.9184	1495	0.7188
Alt2_M03_h7_q1	75752.9869	1495	0.7175
Alt2_M03_h8_q0	75730.3532	1495	0.8033
Alt2_M03_h8_q1	75753.2343	1495	0.795
Alt2_M03_h9_q0	75730.303	1495	0.8922
Alt2_M03_h9_q1	75752.7408	1495	0.8756
Alt2_M04_h6_q0	75681.2923	1495	0.7538
Alt2_M04_h6_q1	75699.038	1495	0.6949

Alt2_M04_h7_q0	75682.4357	1495	0.7042
Alt2_M04_h7_q1	75700.2641	1495	0.6959
Alt2_M04_h8_q0	75682.454	1495	0.7965
Alt2_M04_h8_q1	75699.9105	1495	0.7849
Alt2_M04_h9_q0	75682.2805	1495	0.8925
Alt2_M04_h9_q1	75699.2789	1495	0.8783
Alt3_M02_h6_q0	68218.1084	1575	0.9475
Alt3_M02_h6_q1	68241.5727	1575	0.9393
Alt3_M02_h7_q0	68210.212	1575	0.8445
Alt3_M02_h7_q1	68233.1548	1575	0.8499
Alt3_M02_h8_q0	68215.9259	1575	0.892
Alt3_M02_h8_q1	68239.5832	1575	0.8924
Alt3_M02_h9_q0	68219.6898	1575	0.9383
Alt3_M02_h9_q1	68243.2227	1575	0.9338
Alt3_M03_h6_q0	68207.8818	1575	0.8816
Alt3_M03_h6_q1	68234.4093	1575	0.8639
Alt3_M03_h7_q0	68206.1535	1575	0.7742
Alt3_M03_h7_q1	68232.9219	1575	0.7754
Alt3_M03_h8_q0	68208.5676	1575	0.8369
Alt3_M03_h8_q1	68235.271	1575	0.8331
Alt3_M03_h9_q0	68209.4663	1575	0.9019
Alt3_M03_h9_q1	68235.8202	1575	0.8892
Alt3_M04_h6_q0	68190.6379	1575	0.8102
Alt3_M04_h6_q1	68216.0883	1575	0.7797
Alt3_M04_h7_q0	68191.1463	1575	0.7304
Alt3_M04_h7_q1	68216.8407	1575	0.7269
Alt3_M04_h8_q0	68191.8563	1575	0.8053
Alt3_M04_h8_q1	68217.273	1575	0.7945
Alt3_M04_h9_q0	68191.706	1575	0.8846
Alt3_M04_h9_q1	68216.5771	1575	0.8622
Alt4_M02_h6_q0	74803.9391	1550	0.9254
Alt4_M02_h6_q1	74820.0509	1550	0.9139
Alt4_M02_h7_q0	74799.2911	1550	0.8097
Alt4_M02_h7_q1	74815.7398	1550	0.8108
Alt4_M02_h8_q0	74803.4279	1550	0.865
Alt4_M02_h8_q1	74819.7162	1550	0.8638
Alt4_M02_h9_q0	74805.6629	1550	0.9229
Alt4_M02_h9_q1	74821.7644	1550	0.9163
Alt4_M03_h6_q0	74750.8923	1550	0.8391
Alt4_M03_h6_q1	74768.5918	1550	0.809
Alt4_M03_h7_q0	74750.954	1550	0.7398
Alt4_M03_h7_q1	74768.9806	1550	0.736
Alt4_M03_h8_q0	74752.0416	1550	0.814
Alt4_M03_h8_q1	74769.8106	1550	0.8053
Alt4_M03_h9_q0	74752.2303	1550	0.8934

Alt4_M03_h9_q1	74769.5323	1550	0.8768
Alt4_M04_h6_q0	74684.8068	1550	0.758
Alt4_M04_h6_q1	74704.9356	1550	0.7143
Alt4_M04_h7_q0	74685.9041	1550	0.7078
Alt4_M04_h7_q1	74706.1449	1550	0.7005
Alt4_M04_h8_q0	74685.9624	1550	0.7951
Alt4_M04_h8_q1	74705.818	1550	0.7812
Alt4_M04_h9_q0	74685.6673	1550	0.8875
Alt4_M04_h9_q1	74704.9283	1550	0.865
Alt5_M02_h6_q0	75744.7142	1572	0.8981
Alt5_M02_h6_q1	75767.6881	1572	0.8804
Alt5_M02_h7_q0	75744.7142	1572	0.7742
Alt5_M02_h7_q1	75767.6881	1572	0.778
Alt5_M02_h8_q0	75744.7142	1572	0.8408
Alt5_M02_h8_q1	75767.6881	1572	0.8387
Alt5_M02_h9_q0	75744.7142	1572	0.9103
Alt5_M02_h9_q1	75767.6881	1572	0.8995
Alt5_M03_h6_q0	75744.7142	1572	0.8981
Alt5_M03_h6_q1	75767.6881	1572	0.8804
Alt5_M03_h7_q0	75688.8956	1572	0.7172
Alt5_M03_h7_q1	75706.8754	1572	0.7119
Alt5_M03_h8_q0	75688.8956	1572	0.8016
Alt5_M03_h8_q1	75706.8754	1572	0.7903
Alt5_M03_h9_q0	75688.8956	1572	0.8908
Alt5_M03_h9_q1	75706.8754	1572	0.8719
Alt5_M04_h6_q0	75688.8956	1572	0.7951
Alt5_M04_h6_q1	75706.8754	1572	0.7541
Alt5_M04_h7_q0	75630.3106	1572	0.7006
Alt5_M04_h7_q1	75642.9234	1572	0.6891
Alt5_M04_h8_q0	75630.3106	1572	0.793
Alt5_M04_h8_q1	75642.9234	1572	0.7788
Alt5_M04_h9_q0	75630.3106	1572	0.8896
Alt5_M04_h9_q1	75642.9234	1572	0.8726
Alt6_M02_h6_q0	68809.3289	1461	0.9287
Alt6_M02_h6_q1	68813.828	1461	0.9251
Alt6_M02_h7_q0	68804.7871	1461	0.8112
Alt6_M02_h7_q1	68808.4646	1461	0.8165
Alt6_M02_h8_q0	68809.093	1461	0.8686
Alt6_M02_h8_q1	68813.0359	1461	0.8718
Alt6_M02_h9_q0	68811.5251	1461	0.9247
Alt6_M02_h9_q1	68815.5425	1461	0.9233
Alt6_M03_h6_q0	68768.1102	1461	0.8488
Alt6_M03_h6_q1	68779.177	1461	0.8367
Alt6_M03_h7_q0	68767.8284	1461	0.7468
Alt6_M03_h7_q1	68778.9406	1461	0.7489

Alt6_M03_h8_q0	68769.1973	1461	0.8188
Alt6_M03_h8_q1	68780.3146	1461	0.8165
Alt6_M03_h9_q0	68769.4835	1461	0.8926
Alt6_M03_h9_q1	68780.3656	1461	0.8819
Alt6_M04_h6_q0	68720.0196	1461	0.7932
Alt6_M04_h6_q1	68732.6577	1461	0.7689
Alt6_M04_h7_q0	68720.8039	1461	0.7209
Alt6_M04_h7_q1	68733.5954	1461	0.7178
Alt6_M04_h8_q0	68721.2358	1461	0.8007
Alt6_M04_h8_q1	68733.8156	1461	0.7928
Alt6_M04_h9_q0	68720.986	1461	0.8839
Alt6_M04_h9_q1	68733.1833	1461	0.8672
Alt7_M02_h6_q0	90893.861	1550	0.9469
Alt7_M02_h6_q1	90895.6261	1550	0.9381
Alt7_M02_h7_q0	90885.3986	1550	0.8494
Alt7_M02_h7_q1	90887.2592	1550	0.8526
Alt7_M02_h8_q0	90891.7506	1550	0.8919
Alt7_M02_h8_q1	90893.7501	1550	0.8921
Alt7_M02_h9_q0	90895.4522	1550	0.9375
Alt7_M02_h9_q1	90897.286	1550	0.9327
Alt7_M03_h6_q0	90855.4477	1550	0.8827
Alt7_M03_h6_q1	90859.1861	1550	0.8601
Alt7_M03_h7_q0	90853.8299	1550	0.7728
Alt7_M03_h7_q1	90857.9305	1550	0.772
Alt7_M03_h8_q0	90856.1582	1550	0.8354
Alt7_M03_h8_q1	90860.113	1550	0.8297
Alt7_M03_h9_q0	90857.0491	1550	0.9039
Alt7_M03_h9_q1	90860.581	1550	0.8897
Alt7_M04_h6_q0	90813.7828	1550	0.7944
Alt7_M04_h6_q1	90819.894	1550	0.7541
Alt7_M04_h7_q0	90814.5686	1550	0.7212
Alt7_M04_h7_q1	90820.93	1550	0.7144
Alt7_M04_h8_q0	90814.9947	1550	0.8012
Alt7_M04_h8_q1	90820.9905	1550	0.7884
Alt7_M04_h9_q0	90814.8198	1550	0.8878
Alt7_M04_h9_q1	90820.2414	1550	0.8666
Alt8_M02_h6_q0	75766.1902	1575	0.923
Alt8_M02_h6_q1	75784.0577	1575	0.9023
Alt8_M02_h7_q0	75763.0674	1575	0.785
Alt8_M02_h7_q1	75781.338	1575	0.7861
Alt8_M02_h8_q0	75766.129	1575	0.8515
Alt8_M02_h8_q1	75784.3321	1575	0.8477
Alt8_M02_h9_q0	75767.9076	1575	0.9214
Alt8_M02_h9_q1	75785.7436	1575	0.9112
Alt8_M03_h6_q0	75723.3932	1575	0.815

Alt8_M03_h6_q1	75735.7316	1575	0.7801
Alt8_M03_h7_q0	75724.0476	1575	0.7227
Alt8_M03_h7_q1	75736.6141	1575	0.7188
Alt8_M03_h8_q0	75724.6087	1575	0.8058
Alt8_M03_h8_q1	75736.9821	1575	0.7974
Alt8_M03_h9_q0	75724.646	1575	0.8942
Alt8_M03_h9_q1	75736.6012	1575	0.88
Alt8_M04_h6_q0	75681.4688	1575	0.714
Alt8_M04_h6_q1	75693.1999	1575	0.628
Alt8_M04_h7_q0	75682.6651	1575	0.6986
Alt8_M04_h7_q1	75694.399	1575	0.6844
Alt8_M04_h8_q0	75682.5128	1575	0.792
Alt8_M04_h8_q1	75693.6263	1575	0.7755
Alt8_M04_h9_q0	75682.1965	1575	0.8893
Alt8_M04_h9_q1	75692.719	1575	0.8705
Base_M02_h6_q0	75771.1004	1575	0.9215
Base_M02_h6_q1	75797.8631	1575	0.9098
Base_M02_h7_q0	75767.1543	1575	0.7995
Base_M02_h7_q1	75793.8105	1575	0.8058
Base_M02_h8_q0	75770.8237	1575	0.8591
Base_M02_h8_q1	75797.7066	1575	0.8609
Base_M02_h9_q0	75772.8185	1575	0.9208
Base_M02_h9_q1	75799.5772	1575	0.914
Base_M03_h6_q0	75727.5904	1575	0.8308
Base_M03_h6_q1	75750.4136	1575	0.8005
Base_M03_h7_q0	75727.9207	1575	0.7321
Base_M03_h7_q1	75750.9796	1575	0.7304
Base_M03_h8_q0	75728.7744	1575	0.8106
Base_M03_h8_q1	75751.6341	1575	0.8024
Base_M03_h9_q0	75728.8997	1575	0.8938
Base_M03_h9_q1	75751.2958	1575	0.8766
Base_M04_h6_q0	75679.7505	1575	0.7596
Base_M04_h6_q1	75698.4539	1575	0.705
Base_M04_h7_q0	75681.4528	1575	0.707
Base_M04_h7_q1	75699.6769	1575	0.6981
Base_M04_h8_q0	75681.5101	1575	0.7958
Base_M04_h8_q1	75699.3182	1575	0.7823
Base_M04_h9_q0	75681.2619	1575	0.8893
Base_M04_h9_q1	75698.524	1575	0.8705
Tag_M02_h6_q0	75379.2025	1580	0.9083
Tag_M02_h6_q1	75405.2359	1580	0.8896
Tag_M02_h7_q0	75376.3792	1580	0.7801
Tag_M02_h7_q1	75402.8703	1580	0.783
Tag_M02_h8_q0	75379.1662	1580	0.8458
Tag_M02_h8_q1	75405.7076	1580	0.844

Tag_M02_h9_q0	75380.9073	1580	0.9146
Tag_M02_h9_q1	75406.8582	1580	0.9039
Tag_M03_h6_q0	75340.8393	1580	0.8198
Tag_M03_h6_q1	75362.091	1580	0.7776
Tag_M03_h7_q0	75339.4868	1580	0.7238
Tag_M03_h7_q1	75362.9587	1580	0.72
Tag_M03_h8_q0	75342.0483	1580	0.8072
Tag_M03_h8_q1	75363.2776	1580	0.7957
Tag_M03_h9_q0	75342.0948	1580	0.8933
Tag_M03_h9_q1	75362.7693	1580	0.8738
Tag_M04_h6_q0	75296.3218	1580	0.728
Tag_M04_h6_q1	75313.8366	1580	0.669
Tag_M04_h7_q0	75297.5214	1580	0.7008
Tag_M04_h7_q1	75315.0369	1580	0.6908
Tag_M04_h8_q0	75297.4023	1580	0.7926
Tag_M04_h8_q1	75314.4767	1580	0.7785
Tag_M04_h9_q0	75297.0857	1580	0.8887
Tag_M04_h9_q1	75313.6182	1580	0.8704

Table A1. 1