SUMMARY OF RESULTS OF ASSESSMENT MODELS USED TO DEVELOP MANAGEMENT ADVICE FOR THE 2016 ASSESSMENT OF YELLOWFIN TUNA

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SUMMARY

A stock assessment was conducted for yellowfin tuna in 2016, applying three age-structured models and a non-equilibrium surplus production model to data through 2014. Models used to develop management advice considered two primary sources of scientific uncertainty, the use of index clusters that reflect two disparate hypotheses regarding trends in abundance of yellowfin tuna, and alternative model structures as implemented using four model platforms (i.e. ASPIC, ASPM, SS and VPA). Management advice was developed by combining seven models with equal weighting. The results indicate that 2014 reported catches were below MSY levels, stock biomass was estimated to be about 5% below B_{MSY} (overfished) and fishing mortality rates were about 23% below F_{MSY} (no overfishing). Individual model results are intended to more fully document results considered by the Tropical Tunas Species Group, and are not intended to be used for management purposes.

RÉSUMÉ

Une évaluation du stock d'albacore a été réalisée en 2016, en appliquant trois modèles structurés par âge et un modèle de production excédentaire en conditions de non-équilibre aux données jusqu'en 2014 inclus. Les modèles utilisés pour formuler un avis de gestion ont envisagé deux sources principales d'incertitude scientifique, l'utilisation de grappes d'indices qui reflètent deux hypothèses différentes quant aux tendances de l'abondance de l'albacore, et des structures de modèle alternatives, telles que mises en oeuvre à l'aide de quatre plates-formes de modèle (ASPIC, ASPM, SS et VPA). L'avis de gestion a été formulé en combinant sept modèles dotés d'une pondération égale. Les résultats indiquent que les prises déclarées en 2014 étaient en dessous des niveaux de la PME, la biomasse estimée du stock était d'environ 5% en dessous de B_{PME} (surexploitée) et les taux de mortalité par pêche se situaient à environ 23% en dessous de F_{PME} (ne faisant pas l'objet de surpêche). Les résultats des modèles individuels sont censés documenter plus complètement les résultats examinés par le groupe d'espèces sur les thonidés tropicaux et ils ne sont pas censés être utilisés à des fins de gestion.

RESUMEN

En 2016 se realizó una evaluación del stock de rabil, aplicando tres modelos estructurados por edad y un modelo de producción excedente en condición de no equilibrio a los datos de captura disponibles hasta 2014 inclusive. Los modelos utilizados para desarrollar el asesoramiento de ordenación consideraron dos fuentes principales de incertidumbre científica, el uso de conglomerados de índices que reflejan dos hipótesis diferentes con respecto a las tendencias en la abundancia de rabil y estructuras de modelo alternativas, como las implementadas utilizando cuatro plataformas de modelación (ASPIC, ASPM, SS y VPA). El asesoramiento en materia de ordenación se elaboró combinando siete modelos con una ponderación igual. Los resultados indican que las capturas declaradas de 2014 eran inferiores a los niveles del RMS, que la biomasa del stock se estimó en aproximadamente un 5% inferior a B_{RMS} (sobrepescado) y que las tasas de mortalidad por pesca se situaban en un nivel aproximadamente un 23% inferior al de F_{RMS} (sin sobrepesca). Los resultados del modelo individual están pensados para documentar mejor los resultados considerados por el Grupo de especies de túnidos tropicales y no están pensados para ser utilizados con fines de ordenación.

KEYWORDS

Yellowfin Tuna, stock assessment, fishery management

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1. Introduction

A full stock assessment for yellowfin tuna was conducted in 2016, at which time data inputs through 2014 were available. A summary of the assessment results used to develop management advice is available in the 2016 SCRS Report (Anon. 2016a; Section 8.1). Readers interested in a more complete summary of the state of knowledge on yellowfin tuna stock status should consult the detailed report of the 2016 ICCAT Yellowfin Tuna Stock Assessment Session (Anon. 2016b, and SCRS/2016/207).

As had been done in previous stock assessments (e.g. Anon. 2011), stock status was evaluated using both surplus production and age-structured models. Management advice was developed using a joint distribution of the results of seven models (ASPIC Cluster 1; ASPM-Clusters 1 and 2, VPA Clusters 1 and 2, SS Clusters 1 and 2), weighted equally. Additional uncertainties in growth, age-slicing, mortality, index selection and data weighting were explored in sensitivity runs which are fully described in the report of the 2016 ICCAT Yellowfin Stock Assessment Session (Anon. 2016b).

The full results of all individual models were not available at the conclusion of the 2016 ICCAT Yellowfin Tuna Stock Assessment meeting (Anon. 2016b) and are not contained in the Report of the SCRS Meeting (Anon., 2016a) which summarizes the combined model results used to develop management advice. Therefore, this document was submitted to more fully document the individual model results considered by the Tropical Tunas Species Group.

2. Methods

Models used to develop management advice considered two primary sources of scientific uncertainty, the use of index clusters (**Figure 1**) that reflect two disparate hypotheses regarding trends in abundance of yellowfin tuna, and alternative model structures as implemented using four model platforms (ASPIC, ASPM, VPA and SS). Surplus production models (ASPIC) that used cluster 2 indices did not converge and were not further evaluated. Model specifications and data inputs are fully described in Anon. 2016b and SCRS/2016/207 (VPA).

3. Results

Trends in biomass (**Figure 2**) and fishing mortality (**Figure 3**), relative to the levels that produce maximum sustainable yield (MSY), were generally similar for all models used to develop management advice, although some differences in current stock status were noted. Model specific Kobe status plots (**Figure 4**), with the annual trajectories of stock status, indicate that for most models the 2014 stock status was near B_{MSY} and below F_{MSY}. Approximate annual trajectories of stock status are summarized (**Figure 4**), but should be interpreted with caution because they are not adjusted for known changes in selectivity (Anon. 2016a).

Model estimates of MSY (**Figure 5**) were similar across all models (median =126,304; 80% Confidence Interval = 119,100 - 151,255 t). Estimates of total biomass in 2014 (**Figure 6**) were more variable (median = 464,712 t; 80% CI = 308,287 – 731,485 t), but appear consistent with other model results including stock trends, MSY and current stock status. Current estimates of MSY are conditioned on current selectivity patterns, and are likely to be below what was achieved in past decades because overall selectivity has shifted to smaller fish (Anon. 2016b). The impact of this change in selectivity on estimates of MSY is clearly seen in the results from age structured models (e.g. **Figure 7.**)

Bootstrapped estimates of the current stock status, median stock status and marginal densities in B/B_{MSY} and F/F_{MSY} for the seven individual models are shown in **Figure 8,** and for the combined model in **Figure 9**. Pie charts summarizing the current stock status (i.e. percentage of bootstraps in each Kobe quadrant) varied by model (**Figure 10**). When the uncertainty around the point estimates from all models combined is taken into account, there was an estimated 45.5% chance that the stock was healthy (not overfished and overfishing not occurring) in 2014, a 41.2% probability that the stock was overfished, but not experiencing overfishing and a 13.3% chance that the stock was both overfished and undergoing overfishing (**Figure 11**).

Projections conducted in 2016 considered a number of constant catch scenarios (**Figures 12-13**) from 50,000 to 150,000 t. The SS, VPA and ASPIC projections applied an assumed catch of 110,337 (2015 estimate with carry-overs) to 2015 and 2016, prior to the application of the constant TACs of 50,000 to 150,000 t in 2017-2024. Due to a software constraint, ASPM projections applied constant TACs beginning in 2015. In most cases (SS Cluster 2 is an exception), catches less than 120,000 t led to, or maintained a healthy stock status through 2024. Bootstrap estimates of projected SSB/SSB_{MSY} and F/F_{MSY} support the current TAC of 110,000 t (**Figure 14-15**). Catches above this level have an increasing chance of reducing the stock to levels below B_{MSY} and/or causing overfishing ($F<F_{MSY}$).

The results from the seven individual models were summarized to produce estimated probabilities of achieving the Convention objectives ($B>B_{MSY}$, $F<F_{MSY}$), for a given level of constant catch, for each year up to 2024 (**Tables 1-7**). The probability of maintaining or building to healthy stock status by 2024 ranged from 110,000 m for SS Cluster 2 to 150,000 t for ASPM Cluster 1. In general, index Cluster 1 models supported somewhat higher catches than Cluster 2 models.

The results of all seven models were combined with equal weighting to develop the 2016 management advice (**Table 8**). According to the combined model results, catches of 120,000 t or less are consistent with Convention objectives. Maintaining catch levels at the current TAC of 110,000 t is expected to maintain healthy stock status ($B>B_{MSY}$, $F<F_{MSY}$) through 2024 with at least 68% probability, increasing to 97% by 2024. This result is similar to the previous assessment result (Anon. 2011) which indicated that catch levels of 110,000 t were expected to lead to, or maintain healthy stock status through 2017 with a at least 64% probability, and with a 77% by 2024.

4. Conclusions

This document can be used to better understand the results and behavior of the seven stock assessment models were used to develop the 2016 management advice for Atlantic yellowfin tuna. The ICCAT Subcommittee on Research and Statistics (SCRS) does not support the use of any individual model to inform management as this is an inadequate representation of two major sources of scientific uncertainty (i.e. abundance trends and model assumptions/structure) examined by the group. The 2016 management advice was developed using the combined results of the seven assessment models weighted equally. These results (Anon. 2016a) were adopted by the ICCAT Subcommittee on Research and Statistics (SCRS) in October 2016. They alone represent the consensus recommendations of the ICCAT SCRS.

References

Anon. 2011. Report of the Standing Committee on Research and Statistics (SCRS); Section 8.1 YFT Executive Summary.

Anon. 2016a. Report of the Standing Committee on Research and Statistics (SCRS); Section 8.1 YFT Executive Summary.

Anon. 2016b. Report of the 2016 ICCAT Yellowfin tuna data preparatory meeting. San Sebastián, Spain, March 7 to 11, 2016, 31 p.

Table 1. Kobe II matrices giving the probability that $F<F_{MSY}$, $B>B_{MSY}$ and the joint probability of $F<F_{MSY}$ and $B>B_{MSY}$, in given years, for various constant catch levels based the **ASPIC** model that used index **Cluster 1**.

a) Probability that F < FMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	100%	100%	100%	100%	100%	100%	100%	100%
80,000	100%	100%	100%	100%	100%	100%	100%	100%
90,000	100%	100%	100%	100%	100%	100%	100%	100%
100,000	99%	100%	100%	100%	100%	100%	100%	100%
110,000	93%	96%	98%	99%	100%	100%	100%	100%
120,000	77%	79%	81%	83%	86%	87%	89%	91%
130,000	55%	53%	51%	50%	49%	47%	43%	42%
140,000	32%	28%	25%	20%	17%	15%	13%	11%
150,000	19%	15%	12%	9%	7%	6%	5%	4%

b) Probability that B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	65%	86%	97%	100%	100%	100%	100%	100%
70,000	65%	82%	94%	99%	100%	100%	100%	100%
80,000	65%	79%	92%	98%	100%	100%	100%	100%
90,000	65%	77%	88%	94%	98%	100%	100%	100%
100,000	65%	73%	81%	89%	94%	97%	99%	100%
110,000	65%	71%	76%	80%	86%	90%	93%	96%
120,000	65%	68%	70%	71%	73%	75%	78%	80%
130,000	65%	64%	63%	62%	60%	58%	56%	54%
140,000	65%	61%	54%	49%	43%	39%	32%	27%
150,000	69%	60%	50%	41%	31%	26%	19%	14%

c) Joint probability that F < FMSY and B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	65%	86%	97%	100%	100%	100%	100%	100%
70,000	65%	82%	94%	99%	100%	100%	100%	100%
80,000	65%	79%	92%	98%	100%	100%	100%	100%
90,000	65%	77%	88%	94%	98%	100%	100%	100%
100,000	65%	73%	81%	89%	94%	97%	99%	100%
110,000	65%	71%	76%	80%	86%	90%	93%	96%
120,000	65%	68%	70%	71%	73%	75%	78%	80%
130,000	55%	53%	51%	50%	49%	47%	43%	42%
140,000	32%	28%	25%	20%	17%	15%	13%	11%
150,000	19%	15%	12%	9%	7%	6%	5%	4%

Table 2. Kobe II matrices giving the probability that $F<F_{MSY}$, $B>B_{MSY}$ and the joint probability of $F<F_{MSY}$ and $B>B_{MSY}$, in given years, for various constant catch levels based the **ASPM** model that used index **Cluster 1**.

a) Probability that $F < F_{MSY}$

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	100%	100%	100%	100%	100%	100%	100%	100%
80,000	99%	100%	100%	100%	100%	100%	100%	100%
90,000	99%	100%	100%	100%	100%	100%	100%	100%
100,000	96%	99%	100%	100%	100%	100%	100%	100%
110,000	91%	97%	99%	99%	100%	100%	100%	100%
120,000	80%	90%	97%	99%	99%	99%	99%	100%
130,000	67%	77%	90%	93%	95%	98%	99%	99%
140,000	49%	64%	76%	81%	84%	88%	92%	94%
150,000	37%	47%	56%	62%	65%	70%	74%	78%

b) Probability that B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	97%	100%	100%	100%	100%	100%	100%	100%
70,000	95%	99%	100%	100%	100%	100%	100%	100%
80,000	93%	98%	100%	100%	100%	100%	100%	100%
90,000	89%	98%	100%	100%	100%	100%	100%	100%
100,000	86%	95%	99%	100%	100%	100%	100%	100%
110,000	79%	92%	99%	99%	100%	100%	100%	100%
120,000	71%	86%	97%	99%	99%	99%	100%	100%
130,000	64%	76%	93%	96%	98%	99%	99%	99%
140,000	57%	69%	84%	91%	94%	95%	97%	98%
150,000	50%	61%	73%	79%	83%	88%	90%	91%

c) Joint probability that F < FMSY and B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	97%	100%	100%	100%	100%	100%	100%	100%
70,000	95%	99%	100%	100%	100%	100%	100%	100%
80,000	93%	98%	100%	100%	100%	100%	100%	100%
90,000	89%	98%	100%	100%	100%	100%	100%	100%
100,000	86%	95%	99%	100%	100%	100%	100%	100%
110,000	78%	92%	99%	99%	100%	100%	100%	100%
120,000	68%	84%	96%	99%	99%	99%	99%	100%
130,000	58%	72%	89%	93%	95%	98%	99%	99%
140,000	47%	62%	73%	81%	84%	88%	92%	94%
150,000	36%	45%	55%	61%	65%	70%	74%	78%

Table 3. Kobe II matrices giving the probability that $F<F_{MSY}$, $B>B_{MSY}$ and the joint probability of $F<F_{MSY}$ and $B>B_{MSY}$, in given years, for various constant catch levels based the **ASPM** model that used index **Cluster 2**.

a) Probability that F < FMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	99%	100%	100%	100%	100%	100%	100%	100%
70,000	97%	99%	100%	100%	100%	100%	100%	100%
80,000	93%	98%	99%	99%	99%	100%	100%	100%
90,000	85%	93%	98%	99%	99%	99%	99%	99%
100,000	77%	85%	93%	94%	95%	97%	98%	98%
110,000	65%	76%	84%	87%	89%	92%	93%	94%
120,000	51%	64%	74%	77%	80%	82%	85%	87%
130,000	41%	49%	61%	65%	68%	71%	74%	76%
140,000	31%	39%	43%	48%	52%	56%	58%	60%
150,000	24%	28%	31%	34%	36%	39%	41%	43%

b) Probability that B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	78%	91%	98%	99%	100%	100%	100%	100%
70,000	73%	86%	97%	99%	99%	100%	100%	100%
80,000	69%	83%	95%	97%	99%	99%	99%	99%
90,000	64%	77%	90%	95%	96%	98%	99%	99%
100,000	59%	72%	84%	89%	93%	95%	96%	97%
110,000	54%	64%	78%	83%	87%	89%	92%	93%
120,000	49%	58%	72%	77%	80%	82%	84%	87%
130,000	43%	48%	62%	68%	70%	74%	76%	78%
140,000	38%	43%	50%	55%	59%	62%	66%	67%
150,000	34%	36%	43%	45%	46%	48%	50%	52%

c) Joint probability that F < FMSY and B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	78%	91%	98%	99%	100%	100%	100%	100%
70,000	73%	86%	97%	99%	99%	100%	100%	100%
80,000	69%	83%	95%	97%	99%	99%	99%	99%
90,000	64%	77%	90%	95%	96%	98%	99%	99%
100,000	58%	72%	84%	89%	93%	94%	96%	97%
110,000	53%	64%	78%	83%	86%	89%	92%	93%
120,000	45%	55%	70%	75%	78%	80%	83%	85%
130,000	37%	44%	56%	63%	66%	70%	72%	75%
140,000	29%	38%	41%	47%	50%	55%	57%	59%
150,000	23%	27%	31%	33%	35%	38%	39%	42%

Table 4. Kobe II matrices giving the probability that $F<F_{MSY}$, $B>B_{MSY}$ and the joint probability of $F<F_{MSY}$ and $B>B_{MSY}$, in given years, for various constant catch levels based the **VPA** model that used index **Cluster 1**.

a) Probability that F < FMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	100%	100%	100%	100%	100%	100%	100%	100%
80,000	100%	100%	100%	100%	100%	100%	100%	100%
90,000	99%	100%	100%	100%	100%	100%	100%	100%
100,000	97%	98%	99%	99%	100%	100%	100%	100%
110,000	91%	92%	94%	95%	97%	98%	97%	99%
120,000	77%	75%	76%	75%	75%	75%	73%	71%
130,000	54%	46%	40%	36%	31%	27%	22%	21%
140,000	31%	21%	13%	7%	5%	3%	3%	2%
150,000	14%	6%	2%	1%	0%	0%	0%	0%

b) Probability that B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	81%	96%	100%	100%	100%	100%	100%	100%
70,000	80%	95%	99%	100%	100%	100%	100%	100%
80,000	80%	93%	98%	99%	100%	100%	100%	100%
90,000	78%	91%	97%	99%	99%	100%	100%	100%
100,000	77%	87%	92%	96%	98%	98%	99%	99%
110,000	76%	81%	85%	88%	92%	94%	95%	96%
120,000	75%	75%	75%	75%	76%	75%	75%	73%
130,000	74%	68%	62%	54%	48%	43%	37%	32%
140,000	73%	59%	44%	30%	21%	14%	9%	7%
150,000	71%	51%	31%	15%	7%	2%	2%	1%

c) Joint probability that F < FMSY and B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	81%	96%	100%	100%	100%	100%	100%	100%
70,000	80%	95%	99%	100%	100%	100%	100%	100%
80,000	80%	93%	98%	99%	100%	100%	100%	100%
90,000	78%	91%	97%	99%	99%	100%	100%	100%
100,000	77%	87%	92%	96%	98%	98%	99%	99%
110,000	76%	80%	85%	88%	92%	94%	95%	96%
120,000	73%	71%	71%	71%	73%	72%	70%	68%
130,000	54%	46%	40%	35%	31%	26%	22%	20%
140,000	31%	21%	13%	7%	5%	3%	3%	2%
150,000	14%	6%	2%	1%	0%	0%	0%	0%

Table 5. Kobe II matrices giving the probability that $F<F_{MSY}$, $B>B_{MSY}$ and the joint probability of $F<F_{MSY}$ and $B>B_{MSY}$, in given years, for various constant catch levels based the **VPA** model that used index **Cluster 2**.

a) Probability that F < FMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	100%	100%	100%	100%	100%	100%	100%	100%
80,000	100%	100%	100%	100%	100%	100%	100%	100%
90,000	99%	99%	100%	100%	100%	100%	100%	100%
100,000	98%	99%	99%	99%	99%	99%	100%	100%
110,000	96%	97%	98%	98%	98%	99%	99%	99%
120,000	94%	94%	95%	94%	95%	95%	95%	96%
130,000	88%	87%	85%	85%	85%	85%	83%	82%
140,000	80%	75%	71%	69%	64%	60%	58%	51%
150,000	69%	57%	49%	42%	36%	31%	26%	23%

b) Probability that B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	88%	97%	99%	100%	100%	100%	100%	100%
70,000	88%	96%	99%	99%	100%	100%	100%	100%
80,000	88%	95%	98%	99%	100%	100%	100%	100%
90,000	88%	94%	97%	98%	99%	99%	99%	100%
100,000	87%	93%	96%	97%	98%	99%	99%	99%
110,000	86%	90%	93%	96%	96%	97%	97%	98%
120,000	86%	89%	90%	92%	93%	94%	94%	95%
130,000	85%	87%	86%	86%	85%	85%	85%	83%
140,000	84%	84%	81%	77%	72%	70%	66%	63%
150,000	84%	79%	72%	64%	56%	49%	43%	36%

c) Joint probability that F < FMSY and B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	88%	97%	99%	100%	100%	100%	100%	100%
70,000	88%	96%	99%	99%	100%	100%	100%	100%
80,000	88%	95%	98%	99%	100%	100%	100%	100%
90,000	88%	94%	97%	98%	99%	99%	99%	100%
100,000	87%	93%	96%	97%	98%	99%	99%	99%
110,000	86%	90%	93%	96%	96%	97%	97%	98%
120,000	86%	88%	90%	92%	92%	93%	94%	94%
130,000	83%	83%	83%	81%	82%	82%	81%	80%
140,000	78%	73%	69%	66%	62%	59%	57%	50%
150,000	68%	56%	49%	41%	35%	31%	25%	22%

Table 6. Kobe II matrices giving the probability that $F<F_{MSY}$, $B>B_{MSY}$ and the joint probability of $F<F_{MSY}$ and $B>B_{MSY}$, in given years, for various constant catch levels based the **SS** model that used index **Cluster 1**.

a) Probability that F < FMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	100%	100%	100%	100%	100%	100%	100%	100%
80,000	100%	100%	100%	100%	100%	100%	100%	100%
90,000	100%	100%	100%	100%	100%	100%	100%	100%
100,000	100%	100%	100%	100%	100%	100%	100%	100%
110,000	100%	100%	100%	100%	100%	100%	100%	100%
120,000	100%	100%	100%	100%	100%	100%	100%	100%
130,000	99%	99%	97%	88%	69%	44%	23%	9%
140,000	91%	79%	41%	7%	0%	0%	0%	0%
150,000	64%	27%	2%	0%	0%	0%	0%	0%

b) Probability that B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	100%	100%	100%	100%	100%	100%	100%	100%
80,000	100%	100%	100%	100%	100%	100%	100%	100%
90,000	100%	100%	100%	100%	100%	100%	100%	100%
100,000	100%	100%	100%	100%	100%	100%	100%	100%
110,000	100%	100%	100%	100%	100%	100%	100%	100%
120,000	100%	100%	100%	100%	100%	100%	100%	100%
130,000	100%	100%	100%	100%	99%	95%	88%	72%
140,000	100%	100%	100%	97%	76%	34%	7%	0%
150,000	100%	100%	98%	75%	14%	0%	0%	0%

c) Joint probability that F < FMSY and B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	100%	100%	100%	100%	100%	100%	100%	100%
80,000	100%	100%	100%	100%	100%	100%	100%	100%
90,000	100%	100%	100%	100%	100%	100%	100%	100%
100,000	100%	100%	100%	100%	100%	100%	100%	100%
110,000	100%	100%	100%	100%	100%	100%	100%	100%
120,000	100%	100%	100%	100%	100%	100%	100%	100%
130,000	99%	99%	97%	88%	69%	44%	23%	9%
140,000	91%	79%	41%	7%	0%	0%	0%	0%
150,000	64%	27%	2%	0%	0%	0%	0%	0%

Table 7. Kobe II matrices giving the probability that F<F_{MSY}, B>B_{MSY} and the joint probability of F<F_{MSY} and B>B_{MSY}, in given years, for various constant catch levels based the **SS** model that used index **Cluster 2**.

a) Probability that F < FMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	100%	100%	100%	100%	100%	100%	100%	100%
70,000	99%	100%	100%	100%	100%	100%	100%	100%
80,000	99%	100%	100%	100%	100%	100%	100%	100%
90,000	84%	98%	100%	100%	100%	100%	100%	100%
100,000	72%	92%	98%	98%	99%	100%	100%	100%
110,000	46%	66%	79%	94%	98%	99%	99%	100%
120,000	34%	49%	54%	32%	34%	38%	42%	46%
130,000	6%	7%	4%	7%	4%	2%	1%	1%
140,000	4%	2%	1%	0%	0%	0%	0%	0%
150,000	0%	0%	0%	0%	0%	0%	0%	0%

b) Probability that B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	6%	58%	98%	100%	100%	100%	100%	100%
70,000	5%	42%	91%	100%	100%	100%	100%	100%
80,000	6%	43%	84%	98%	100%	100%	100%	100%
90,000	5%	29%	63%	93%	99%	100%	100%	100%
100,000	7%	29%	58%	68%	86%	95%	99%	99%
110,000	9%	37%	58%	72%	82%	91%	96%	98%
120,000	11%	36%	47%	39%	40%	44%	49%	53%
130,000	9%	26%	26%	18%	13%	8%	6%	4%
140,000	12%	24%	18%	4%	0%	0%	0%	0%
150,000	8%	16%	7%	1%	0%	0%	0%	0%

c) Joint probability that F < FMSY and B> BMSY

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	6%	58%	98%	100%	100%	100%	100%	100%
70,000	5%	42%	91%	100%	100%	100%	100%	100%
80,000	7%	44%	84%	98%	100%	100%	100%	100%
90,000	5%	29%	63%	93%	99%	100%	100%	100%
100,000	7%	29%	57%	68%	86%	95%	99%	99%
110,000	9%	37%	57%	72%	82%	91%	96%	98%
120,000	11%	36%	47%	32%	34%	37%	42%	46%
130,000	5%	7%	4%	7%	4%	2%	1%	1%
140,000	4%	2%	1%	0%	0%	0%	0%	0%
150,000	0%	0%	0%	0%	0%	0%	0%	0%

Table 8. Kobe II matrices giving the probability that $F<F_{MSY}$, $B>B_{MSY}$ and the joint probability of $F<F_{MSY}$ and $B>B_{MSY}$, in given years, for various constant catch levels based the **COMBINED** model results.

a) Probability that $F<F_{MSY}$

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	99%	100%	100%	100%	100%	100%	100%	100%
70,000	99%	99%	100%	100%	100%	100%	100%	100%
80,000	98%	99%	99%	99%	99%	100%	100%	100%
90,000	95%	98%	99%	99%	99%	99%	99%	99%
100,000	91%	96%	98%	98%	99%	99%	99%	99%
110,000	84%	89%	93%	96%	97%	98%	98%	98%
120,000	74%	79%	83%	80%	81%	82%	83%	84%
130,000	60%	61%	62%	62%	58%	54%	51%	48%
140,000	46%	44%	39%	33%	31%	31%	31%	30%
150,000	32%	25%	21%	20%	19%	20%	20%	20%

b) Probability that $B>B_{MSY}$

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	75%	91%	99%	99%	99%	99%	100%	100%
70,000	74%	87%	97%	99%	99%	99%	99%	99%
80,000	73%	86%	96%	99%	99%	99%	99%	99%
90,000	71%	82%	91%	97%	99%	99%	99%	99%
100,000	70%	80%	89%	92%	96%	97%	99%	99%
110,000	68%	78%	85%	90%	93%	95%	96%	97%
120,000	67%	75%	80%	80%	81%	82%	84%	84%
130,000	64%	68%	72%	70%	69%	67%	65%	62%
140,000	63%	64%	63%	59%	53%	46%	40%	38%
150,000	61%	59%	55%	47%	34%	30%	28%	27%

c) Probability that $F<F_{MSY}$ and $B>B_{MSY}$

TAC	2017	2018	2019	2020	2021	2022	2023	2024
60,000	75%	91%	99%	99%	99%	99%	100%	100%
70,000	74%	87%	97%	99%	99%	99%	99%	99%
80,000	73%	86%	96%	99%	99%	99%	99%	99%
90,000	71%	82%	91%	97%	99%	99%	99%	99%
100,000	70%	80%	89%	92%	96%	97%	99%	99%
110,000	68%	78%	85%	90%	92%	95%	96%	97%
120,000	65%	73%	79%	78%	79%	80%	82%	82%
130,000	57%	59%	61%	61%	57%	54%	50%	48%
140,000	45%	44%	38%	33%	31%	31%	31%	30%
150,000	31%	24%	21%	20%	19%	20%	20%	20%

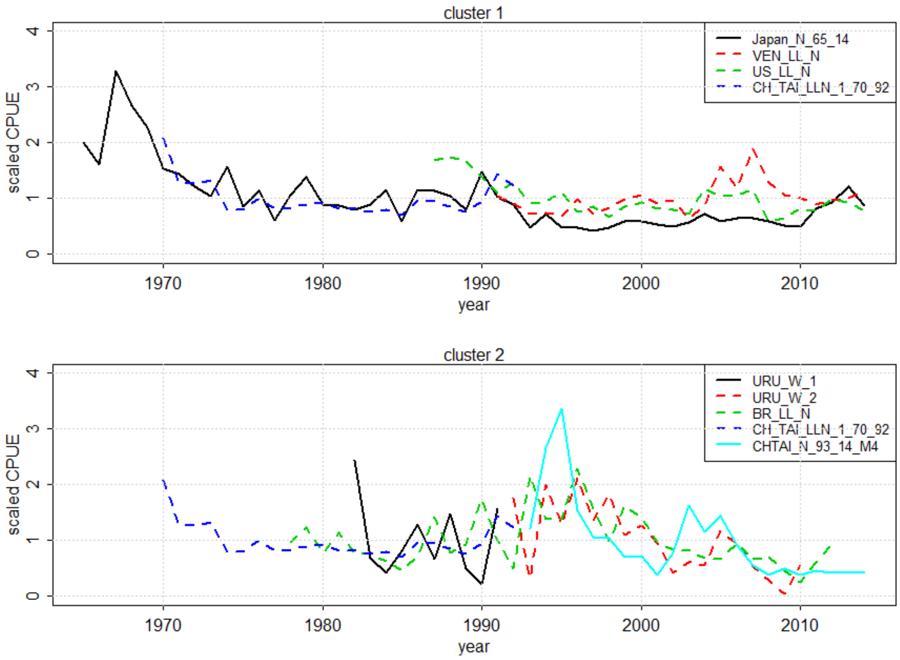

Figure 1. Standardized catch rate trends from cluster 1 (top panel) and cluster 2 (bottom panel) indices of abundance.

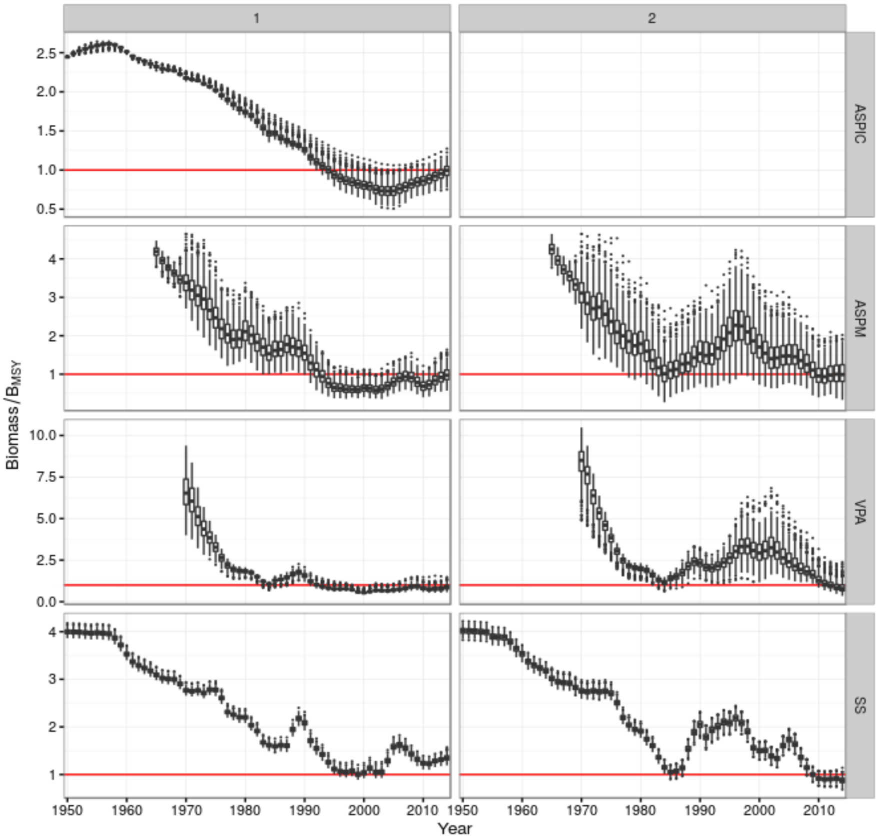

Figure 2. Trajectories of biomass relative to B_{MSY} for ASPIC and SSB relative to SSB_{MSY} for the age based models (ASPM, VPA, SS); Box and whiskers show the bootstrapped confidence intervals. The lower and upper "hinges" correspond to the 25th and 75th percentiles.

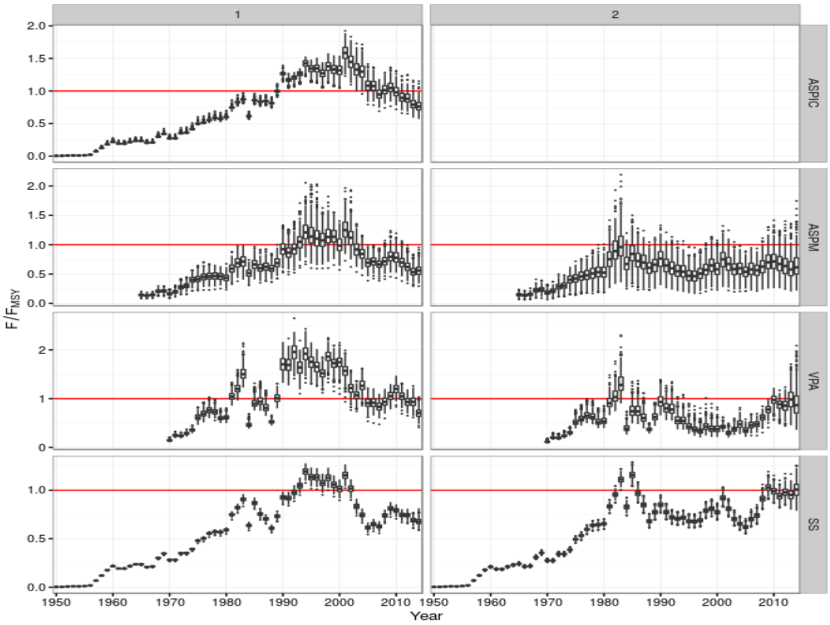

Figure 3. Trajectories of harvest rate relative to F_{MSY} for ASPIC and fishing mortality relative to F_{MSY} for the age based models. Box and whiskers show the bootstrapped confidence intervals. The lower and upper "hinges" correspond to the 25th and 75th percentiles.

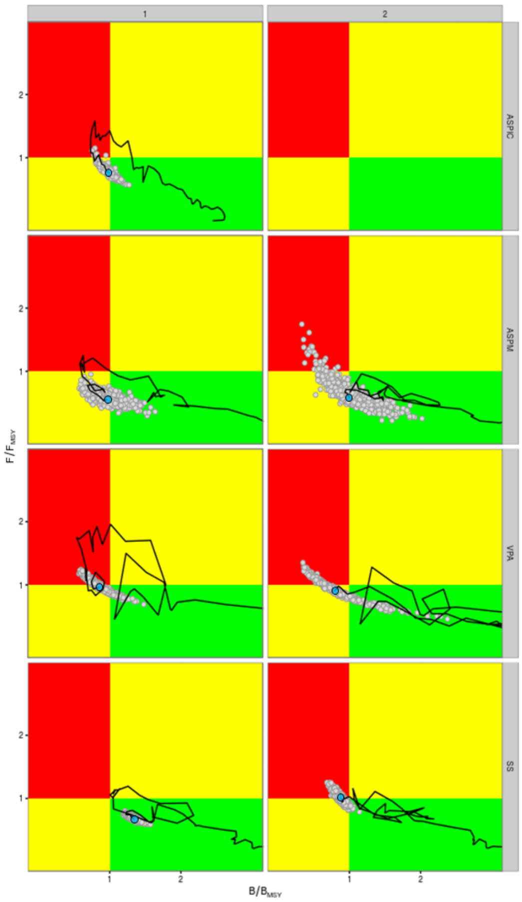

Figure 4. Kobe Status Plot for each model with 500 bootstrap estimates of the uncertainty in current stock status. The trajectories are intended to demonstrate general trends in stock status, but do not account for known changes in selectivity.

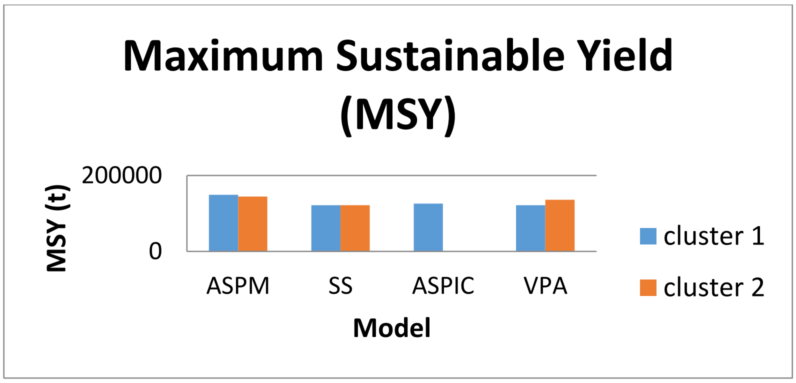

Figure 5. Model estimates of MSY (t).

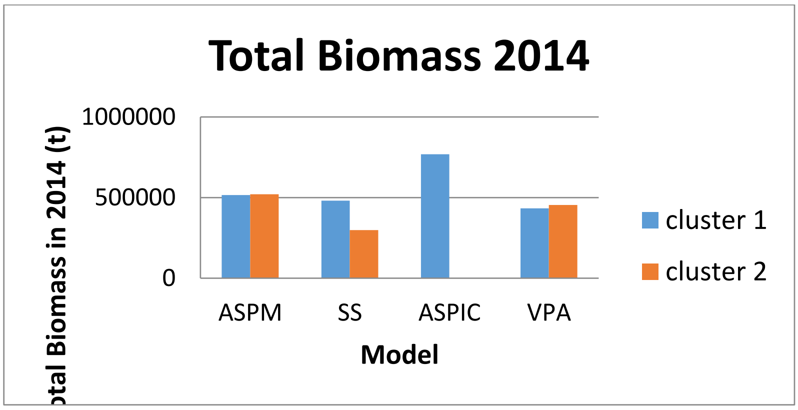

Figure 6. Model estimates of total biomass in 2014 (t).

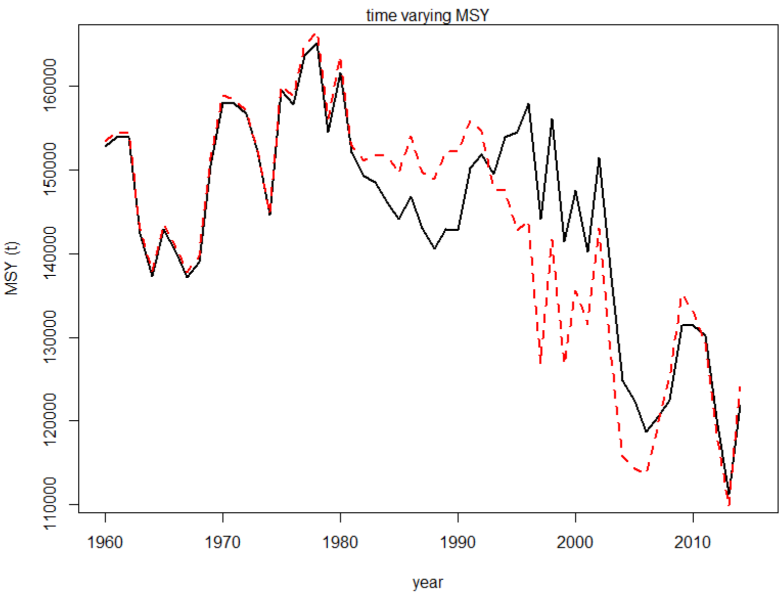

Figure 7. MSY estimated annually from an age structured stock assessment (SS) models using cluster 1 (black) and 2 (broken red line) indices.

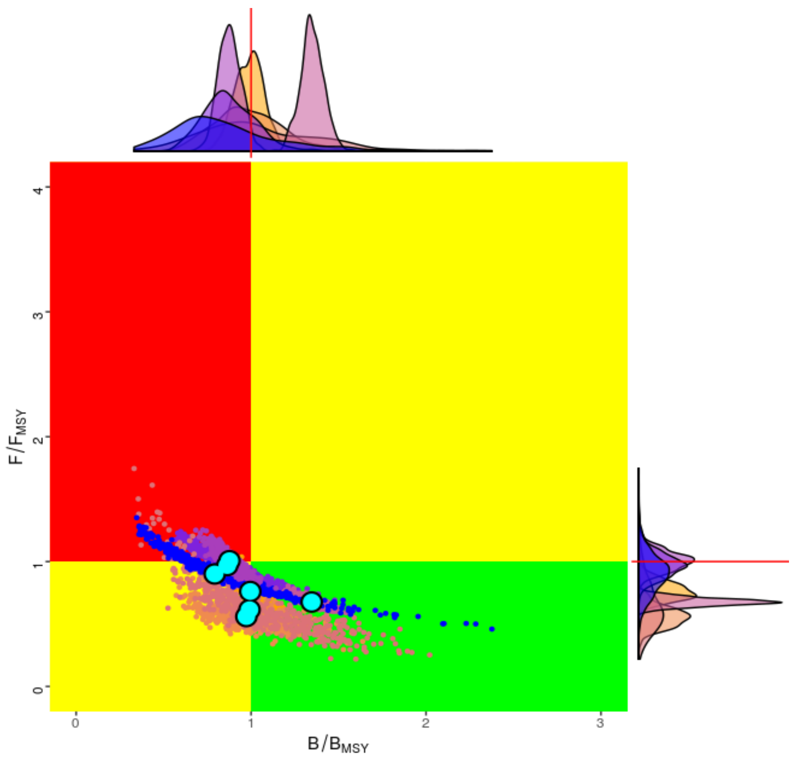

Figure 8. Kobe phase plot for all model runs. Colored points indicate the bootstrap estimates of current stock status (n=500). The blue points are the median stock status estimates from the various models. The marginal densities in B/B_{MSY} and F/F_{MSY}, by model, are shown at the top and right of the figure.

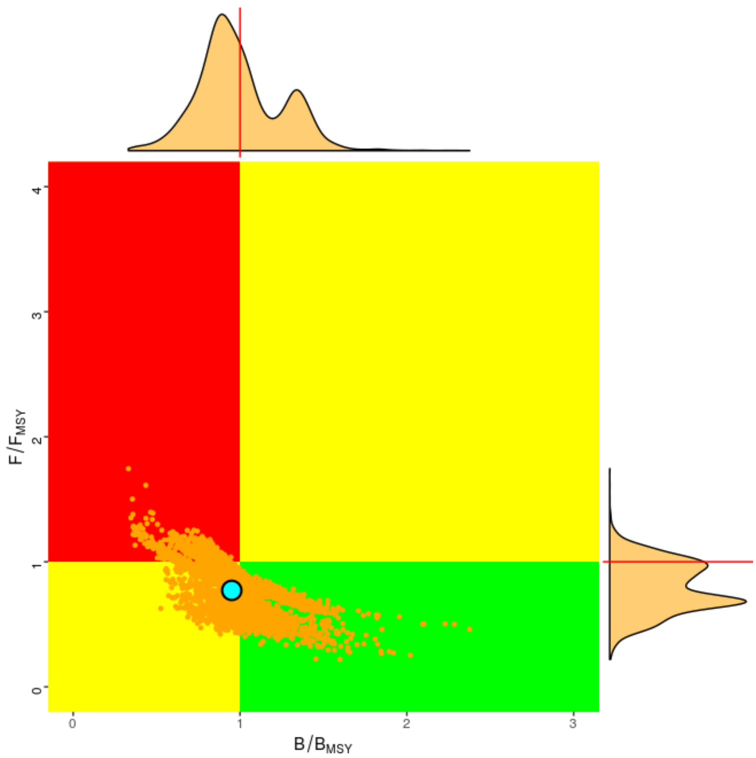

Figure 9. Kobe phase plot for combined model runs. Brown points indicate the bootstrap estimates of current stock status for all models combined, weighted equally (n=3500). The blue point is the median stock status estimate from the combined distribution. The combined marginal densities in B/B_{MSY} and F/F_{MSY}, are shown at the top and right of the figure.

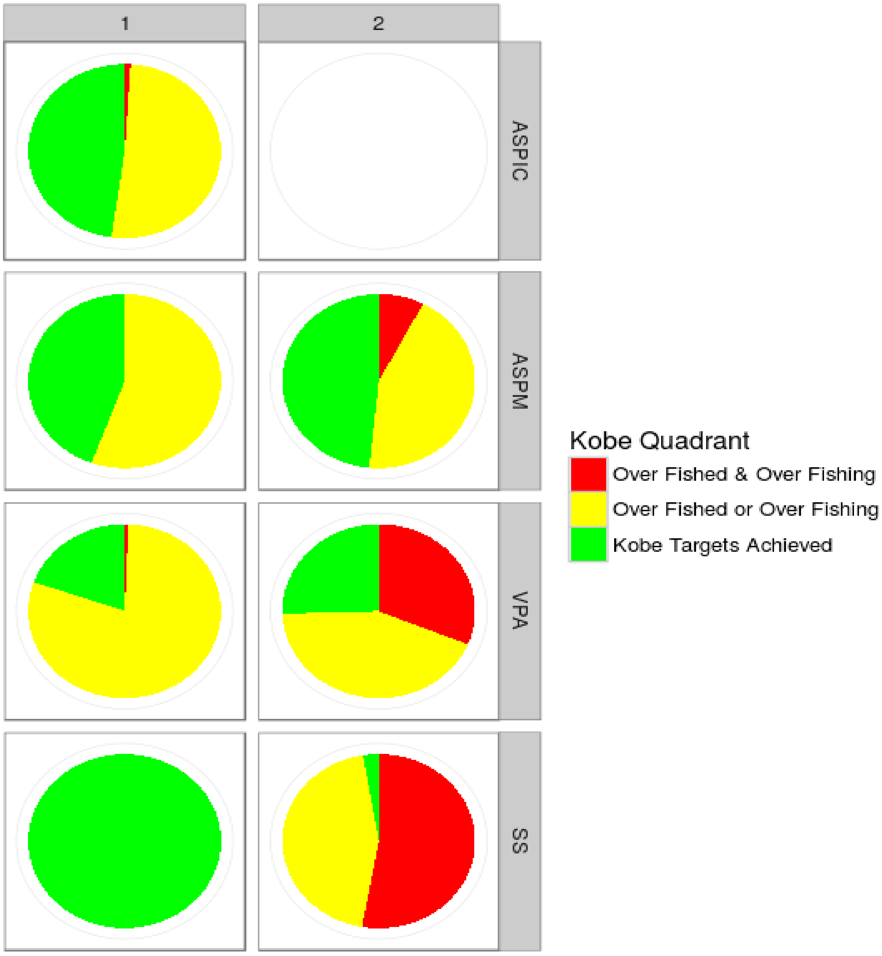

Figure 10. Pie charts representing the proportion of bootstraps located in each Kobe quadrant, by model.

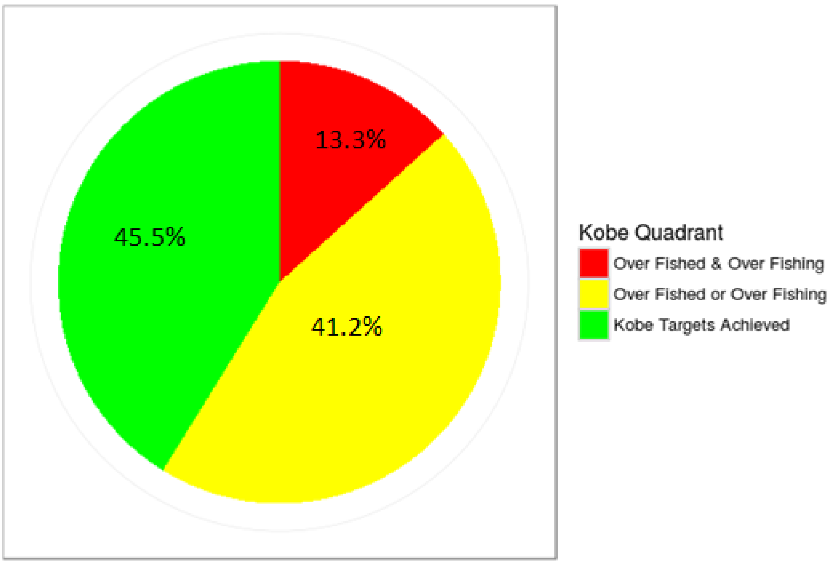

Figure 11. Pie chart representing the proportion of bootstraps located in each Kobe quadrant, for all models combined.

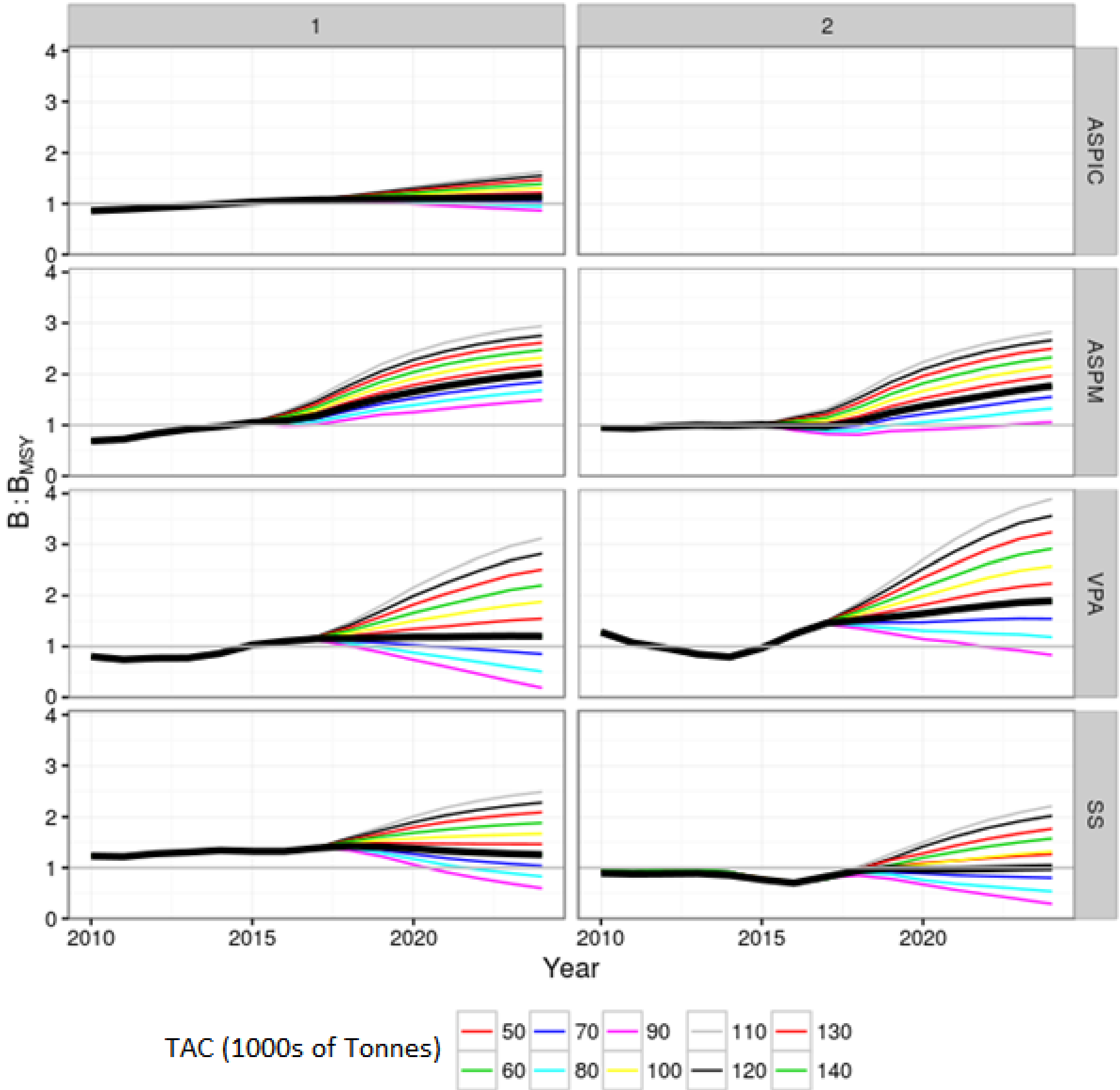

Figure 12. Median B/B_{MSY} (2010 – 2024) for projections of constant TACs of 50,000 to 140,000 t. SS, VPA and ASPIC projections applied an assumed catch of 110,337 (2015 estimate with carry-overs) to 2015 and 2016, prior to the application of the constant TACs of 50,000 to 150,000 t in 2017-2024. Due to a software constraint, ASPM projections applied constant TACs beginning in 2015.

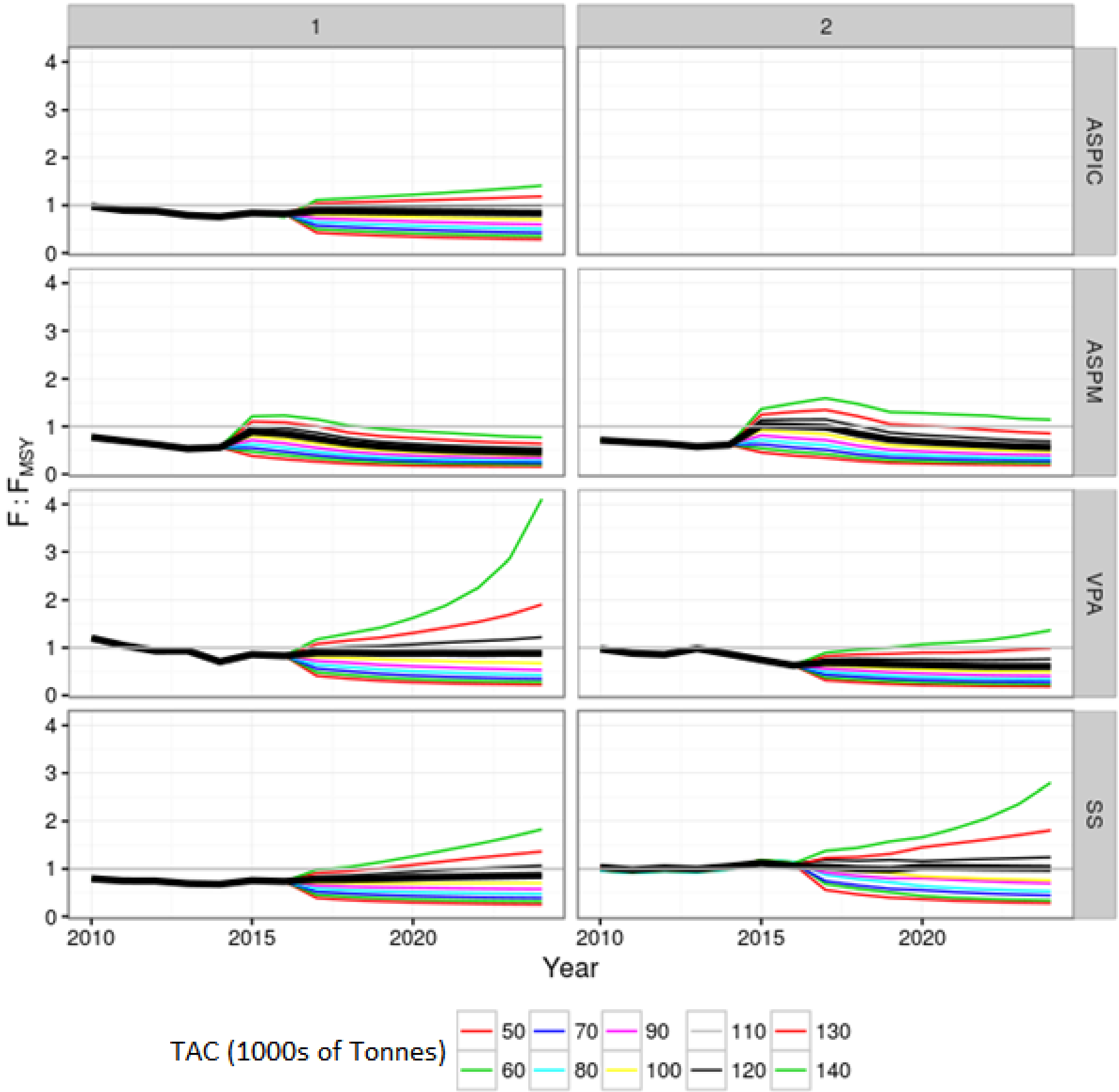

Figure 13. Median F/FMSY (2010 – 2024) for projections of constant TACs of 50,000 to 140,000 t. SS, VPA and ASPIC projections applied an assumed catch of 110,337 (2015 estimate with carry-overs) to 2015 and 2016, prior to the application of the constant TACs of 50,000 to 150,000 t in 2017-2024. Due to a software constraint, ASPM projections applied constant TACs beginning in 2015.

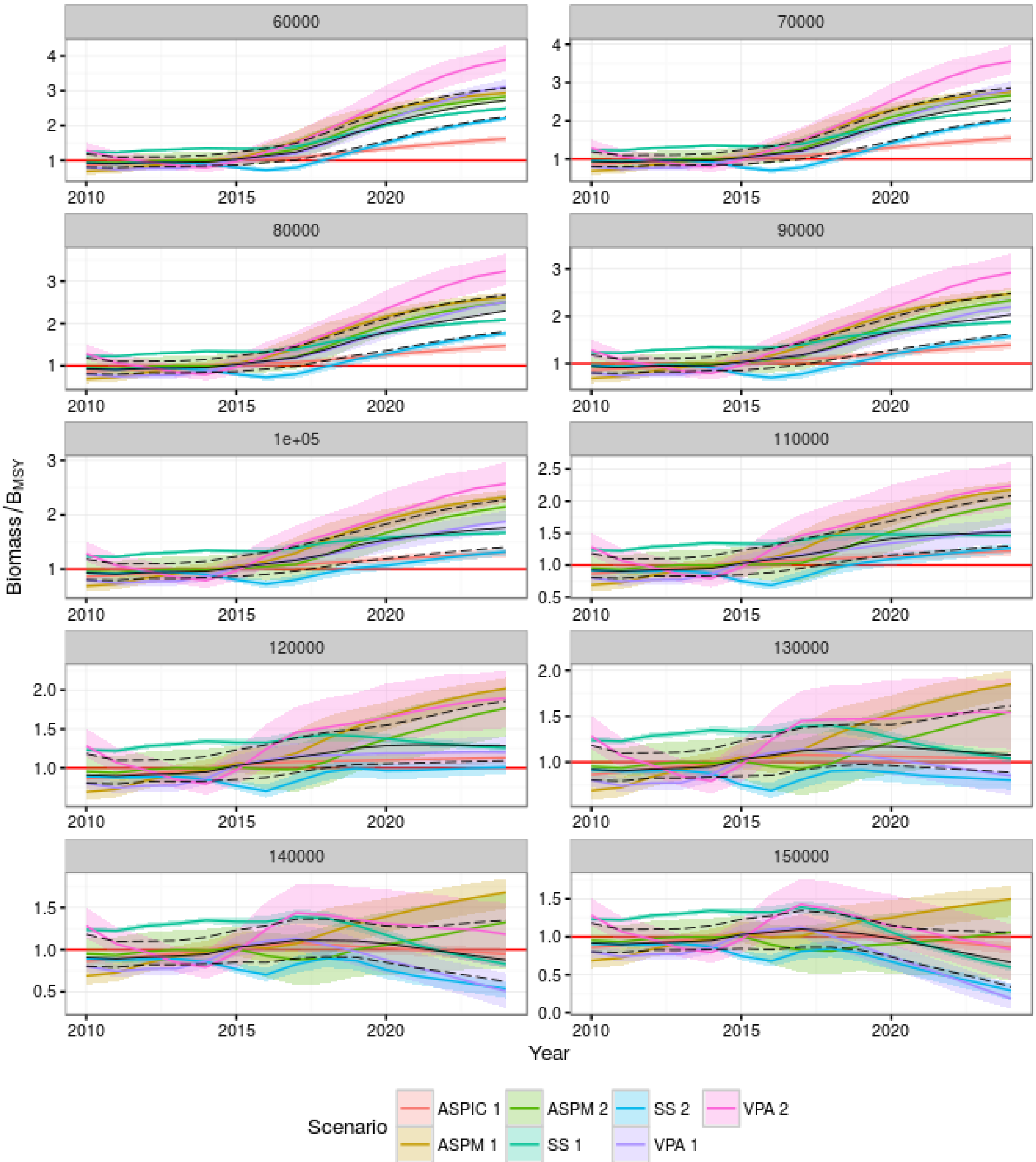

Figure 14. Bootstrapped time series of stock biomass relative to MSY benchmarks under various levels of constant TAC.

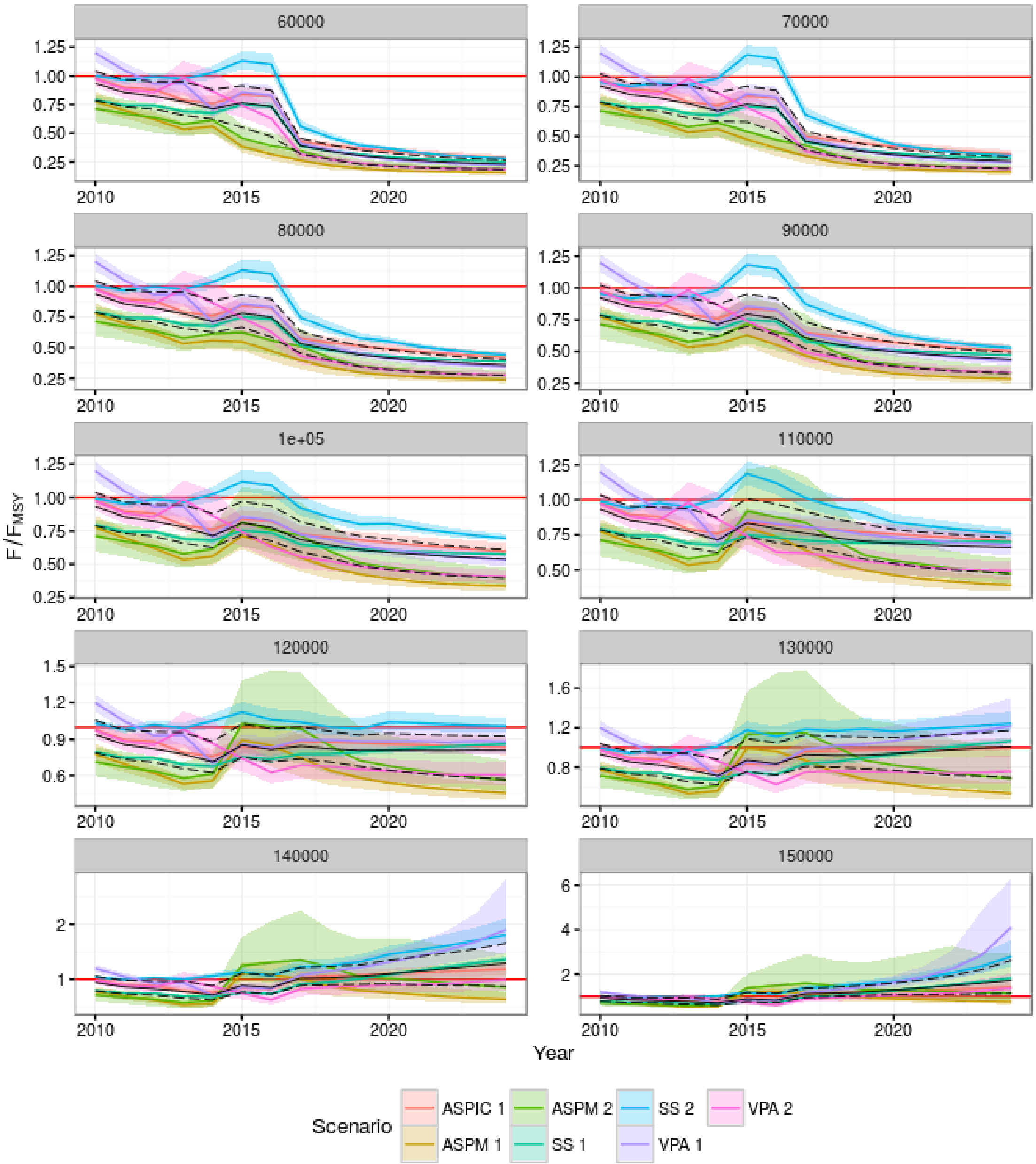

Figure 15. Bootstrapped time series of fishing mortality relative to MSY benchmarks under various levels of constant TAC.