SCRS/2020/150 Collect. Vol. Sci. Pap. ICCAT, 77(2): 832-840 (2020)

DESIGNING AND TESTING A MULTI-STOCK SPATIAL MANAGEMENT PROCEDURE FOR ATLANTIC BLUEFIN TUNA

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SUMMARY

A candidate management procedure to set total allowable catch advice from indices of abundance was designed that has three novel aspects. Firstly, it combines catch rate indices by area and spawning biomass indices by stock to infer regional abundance. This configuration has the advantage that TACs are set according to multiple sources of information and mixing is accounted for, for example allowing TACs in the western area to respond to fluctuations in productivity in the Eastern stock. Secondly, the MP implements a harvest control rule that can account for both stock status (B/B_{MSY}) and exploitation rate (F/F_{MSY}). The advantage of this approach is that for example, a stock that is overfished and recovering (underfishing) does not necessarily incur a TAC reduction. Thirdly, the MP includes protocols for detecting and adjusting for chronic overfishing due to mis-calibration of indices or large reductions in stock productivity. A preliminary test of six variants of the MP was carried out for the 96 operating models of the interim grid and the 12 primary robustness operating models.

RÉSUMÉ

Une procédure de gestion potentielle visant à fixer l'avis concernant le total admissible des captures à partir d'indices d'abondance a été conçue et comporte trois nouveaux aspects. Premièrement, elle combine des indices de taux de capture par zone et des indices de biomasse reproductrice par stock pour calculer l'abondance régionale. Cette configuration présente l'avantage que les TAC sont fixés en fonction de multiples sources d'information et que le mélange est pris en compte, ce qui permet par exemple aux TAC de la zone occidentale de répondre aux fluctuations de la productivité du stock oriental. Deuxièmement, la procédure de gestion met en œuvre une règle de contrôle de l'exploitation qui peut tenir compte à la fois de l'état du stock (B/BPME) et du taux d'exploitation (F/FPME). L'avantage de cette approche est que, par exemple, un stock qui est surexploité et qui se reconstitue (sous-pêche) n'entraîne pas nécessairement une réduction du TAC. Troisièmement, la procédure de gestion comprend des protocoles de détection et d'ajustement de la surpêche chronique due à un mauvais calibrage des indices ou à de fortes réductions de la productivité du stock. Un test préliminaire de six variantes de la procédure de gestion a été effectué pour les 96 modèles opérationnels de la grille provisoire et les 12 principaux modèles opérationnels du test de robustesse.

RESUMEN

Se diseñó un procedimiento de ordenación candidato que establece el asesoramiento sobre el total admisible de captura a partir de índices de abundancia y cuenta con tres aspectos novedosos. En primer lugar, combina los índices de tasa de captura por área y los índices de la biomasa reproductora por stock para deducir la abundancia regional. Esta configuración tiene la ventaja de que los TAC se establecen de acuerdo con múltiples fuentes de información y se tiene en cuenta la mezcla, por ejemplo, permitiendo que los TAC de la zona occidental respondan a fluctuaciones en la productividad del stock oriental. En segundo lugar, el MP implementa una norma de control de la captura que pueda tener en cuenta tanto el estado del stock (B/B_{RMS}) como la tasa de explotación (F/F_{RMS}). La ventaja de este enfoque es que, por ejemplo, un stock que está sobrepescado y recuperándose (infraexplotado) no incurre necesariamente en una reducción del TAC. En tercer lugar, el MP incluye protocolos para detectar y ajustar la sobrepesca crónica debida a una mala calibración de los índices o a grandes reducciones en la productividad del stock. Se llevó a cabo una prueba preliminar de seis variantes del MP para los 96 modelos operativos de la matriz provisional y los 12 principales modelos operativos de la prueba de robustez.

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KEYWORDS

Management Strategy Evaluation,
bluefin tuna, operating model, management procedure

Introduction

The MP approach to managing North Atlantic tuna provides an opportunity to move past the current assessment paradigm where management advice (which is necessarily by East / West area) is based on data that are also distinct by East / West area. Genetics, tagging and microconstituent data have long confirmed that there are at least two spawning stocks of Atlantic bluefin tuna, they exhibit extensive mixing in the Atlantic Ocean outside of their natal spawning grounds in the Gulf of Mexico and Mediterranean and they differ markedly in their magnitude (at unfished levels the Eastern stock is around 6-10 times larger than the Western stock). These observations suggest that if catch advice by area is to be based on estimates of vulnerable biomass in a given area, these should be responsive to varying augmentation from the stock originating from the other side of the ocean.

In this paper I describe a multi-stock, multi-area MP ('MPx') that uses spawning indices to estimate stock-specific vulnerable biomass which in conjunction with assumed rates of mixing is used to predict the vulnerable biomass of each stock in each area (**Figure 1**). These regional estimates of vulnerable biomass are combined with independent regional estimates derived from catch rate indices. Together these indices inform regional vulnerable biomass B, and fishing mortality rate F (since we also have observations of regional catches). TAC adjustments are made according to a novel harvest control rule that uses estimated fishing rate relative to FMSY and vulnerable biomass relative to BMSY to locate the stock at approximately MSY levels. The harvest control rule is intended to be responsive with respect to fluctuations in stock-specific productivity, allowing for increased yields where production is high and throttling of TAC given periods of lower productivity.

Methods

Data smoothing

In order to reduce noise in both indices and catches, the MP uses a polynomial ('loess') smoothing function *S()*. Smoothed catches $\tilde{C}$ and smoothed are (A) and stock (S) indices $\tilde{I}$ are calculated from the raw observed catches C and indices I by area *a* and index type *i*, using the same smoothing parameter ω:

$$\tilde{I}^A_{a,i} = S(I^A_{a,i}, \omega)$$
$$\tilde{I}^S_{a,i} = S(I^S_{a,i}, \omega)$$
$$\tilde{C}_a = S(C_a, \omega)$$

The function is parameterized such that the approximate number of smoothing parameters is a linear function of the length of the time series. The effect of the ratio of smoothing parameters to length of the time series *ω*, is illustrated in **Figure 1**.

Vulnerable biomass and fishing rate estimation

A multi-stock, multi-area management procedure 'MPx', was designed to provide TAC advice in a given time period *t* using Stock biomass indices (I^S) by stock *s* and Catch Rate Indices (I^A) by area *a*, calibrated to current stock assessments of vulnerable biomass *B* (estimates of catchability *q* for stock and area indices) (**Figure 2**). In order to, for example, interpret West area biomass in terms of Eastern stock biomass, an estimate of stock mixing is required $\theta^{mix}_{s=East\_stock,a=West}$ that is the fraction of Eastern stock biomass that can be expected to be vulnerable to fishing in the West area. Where there are more than one spawning stock index ($n_{s,i} > 1$) or more than one area index ($n_{a,i} > 1$) overall biomass estimates were the mean of those from the multiple indices:

(1) $$B^S_{a,t} = \frac{\sum_s \sum_i \tilde{I}^S_{s,i,t} q^S_{s,i} \theta^{mix}_{s,a}}{n_{s,i}}$$

(2) $$B^{A}_{a,t} = \frac{\sum_s \sum_i \tilde{I}^{A}_{a,i,t} q^{A}_{a,i}}{n_{a,i}}$$

The q parameters are calibrated to 2016 estimates spawning biomass (by stock) θ^{S}_{s}, and vulnerable biomass (by area) θ^{A}_{a}:

(3) $$q^{S}_{s} = \frac{\theta^{S}_{s,2016}}{\tilde{I}^{S}_{s,2016}}$$

(4) $$q^{A}_{a} = \frac{\theta^{A}_{a,2016}}{\tilde{I}^{A}_{a,2016}}$$

The estimates of vulnerable biomass B arising from the calibrated indices can be used to estimate the fishing mortality rate using observations of catches C

(5) $$F^{A}_{a,t} = -\ln\left(1 - \frac{C_{a,t}}{B^{A}_{a,t}}\right)$$

(6) $$F^{S}_{a,t} = -\ln\left(1 - \frac{C_{a,t}}{B^{S}_{a,t}}\right)$$

Combining inference from SSB and CPUE indices

Assessment estimates of vulnerable biomass at *MSY* (θ^{BMSY}) can be used to calculate current vulnerable biomass relative to *BMSY*, here inference from catch rate and spawning indices is equally weighted as the geometric mean:

(7) $$\Delta^{B}_{a,t} = exp\left(\frac{1}{2}\left[ln\left(\frac{B^{S}_{a,t}}{\theta^{BMSY}_{a}}\right) + ln\left(\frac{B^{A}_{a,t}}{\theta^{BMSY}_{a}}\right)\right]\right)$$

The same approach was used to combined estimates of F relative to *FMSY*:

(8) $$\Delta^{F}_{a,t} = \exp\left(\frac{1}{2}\left[ln\left(\frac{F^{S}_{a,t}}{\tilde{\theta}^{FMSY}_{a}}\right) + ln\left(\frac{F^{A}_{a,t}}{\tilde{\theta}^{FMSY}_{a}}\right)\right]\right)$$

A harvest control rule for TAC adjustment based on estimates of B/BMSY and F/FMSY

TACs in the following year are based on TAC in the previous time step multiplied by a factor $\varphi_{a,t}$:

(9) $$TAC_{a,t+1} = TAC_{a,t}\ \varphi_{a,t}$$

where the factor $\varphi_{a,t}$ is determined by adjustments for fishing rate $\delta^{F}_{a,t}$ and stock status $\delta^{B}_{a,t}$:

(10) $$\tilde{\varphi}_{a,t} = \delta^{F}_{a,t}\ \delta^{B}_{a,t}$$

The adjustment to F is the inverse of *F*/*FMSY* ($\Delta^{F}_{a,t}$) where the magnitude of the adjustment is determined by β^{F}. The parameter α^{F} controls the target F level where *F*/*FMSY* = 1 and *B*/*BMSY* = 1. For example, at a value of 0.8, the MP deliberately aims to underfish at 80% of *FMSY* when the stock is at *BMSY* and current *F* is *FMSY*. Note that when α^{F}=1 and β^{F} = 1 the F adjustment $\delta^{F}_{a,t}$ is the inverse of $\Delta^{F}_{a,t}$ and hence recommends *FMSY* fishing rate (and depends on the assumption that biomass will be comparable at t+1) (**Figure 3**).

(11) $$\delta^{F}_{a,t} = \alpha^{F}\ exp\left(\beta^{F}\ ln\left(1/\Delta^{F}_{a,t}\right)\right)$$

The adjustment according to biomass is exponentially related to the disparity between current biomass and B_{MSY}. The term $|\Delta^B_{a,t} - 1|$ is the positive absolute difference (modulus). The magnitude of the adjustment for biomass is controlled by the parameter α^B while the (extent of the TAC change for biomass levels far from B_{MSY}) is controlled by the exponent β^B. This is analogous to a traditional harvest control rule (e.g. '40-10') and throttles fishing rates at low stock sizes to speed recovery while also increasing fishing rates at high stock sizes to exploit additional biomass (Figure 3). When α^B = 0 there is no biomass adjustment and $\delta^B_{a,t}$ is invariant to β^B (e.g. Figure 3).

(12)
$$\delta^B_{a,t} = \begin{cases} exp\left[\left(\alpha^B|\Delta^B_{a,t} - 1|\right)^{\beta^B}\right] & 1 < \Delta^B_{a,t} \\ exp\left[-\left(\alpha^B|\Delta^B_{a,t} - 1|\right)^{\beta^B}\right] & \Delta^B_{a,t} \leq 1 \end{cases}$$

This generalized TAC harvest control rule can accommodate a wide range of control schemes of varying sensitivity to estimates of current exploitation rate and stock status (**See Figures 4 and 5**).

TAC adjustment limits

The maximum rate of TAC adjustment is determined by θ^{down} and θ^{up} and the minimum amount is controlled by θ^{min}:

(13)
$$\hat{\varphi}_{a,t} = \begin{cases} \theta^{down} & \tilde{\varphi}_{a,t} < \theta^{down} \\ \tilde{\varphi}_{a,t} & \theta^{down} < \tilde{\varphi}_{a,t} < (1-\theta^{min}) \\ 1 & (1-\theta^{min}) < \tilde{\varphi}_{a,t} < (1+\theta^{min}) \\ \tilde{\varphi}_{a,t} & (1+\theta^{min}) < \tilde{\varphi}_{a,t} < \theta^{up} \\ \theta^{up} & \theta^{up} < \tilde{\varphi}_{a,t} \end{cases}$$

Index recalibration rule

In essence, MPx is a fixed harvest rate policy that sets TACs equal to the indices multiplied by a factor (with some variability due to the harvest control rule). It is possible to detect chronic overfishing caused by miscalibration of the index due to an operating model with much lower biomass scale than assumed by the MP (e.g. recruitment level 2) or due to changes in unfished stock size in the future (e.g. recruitment level 3).

When chronic overfishing occurs from a fixed harvest rate policy, two conditions may simultaneously occur: the index declines whilst catches and the index are also positively correlated. This condition is symptomatic of overfished stock levels to the left side of BMSY in a typical productivity curve (**Figure 2**).

The index calibration rule occurs in each projected year. In each instance the last γ^n years of smoothed catch and spawning biomass indices are extracted. When the slope in the log spawning biomass index is negative a downward adjustment in target FMSY is applied:

$$\tilde{\theta}^{FMSY}_a = \theta^{FMSY}_a \prod_y exp\left(\gamma^a slope\left(\log(\tilde{I}_{y=\{y-4,\ y-3,\ y-2,\ y-1\},a}), \tilde{C}_{\{y-4,\ y-3,\ y-2,\ y-1\},a}\right)\right)$$

Acknowledgments

This work was carried out under the provision of the ICCAT Atlantic Wide Research Programme for Bluefin Tuna (GBYP), funded by the European Union, several ICCAT CPCs, the ICCAT Secretariat and by other entities (see: http://www.iccat.int/GBYP/en/Budget.htm). The contents of this paper do not necessarily reflect the point of view of ICCAT or other funders and in no ways anticipate ICCAT future policy in this area.

Table 1. The input data, parameters of the current default MPx managment procedure.

Description		**Value**
Biomass calculation		
$\mathrm{I}^{S}_{East\_stock}$	Spawning stock biomass index for eastern stock	MED_LAR_SUV (#2), GBYP_AER_SUV_BAR (#5)
$\mathrm{I}^{S}_{West\_stock}$	Spawning stock biomass index for western stock	GOM_LAR_SUV (#4)
I^{A}_{East}	Vulnerable biomass catch rate index for eastern area	MOR_POR_TRAP (#6), JPN_LL_NEATL2 (#7)
I^{A}_{West}	Vulnerable biomass catch rate index for western area	US_RR_177 (#10), JPN_LL_West2 (#12)
θ^{BMSY}_{East}	Eastern area biomass at maximum sustainable yield	800 kt
θ^{BMSY}_{West}	Western area biomass at maximum sustainable yield	20 kt
θ^{FMSY}_{East}	Eastern area harvest rate at MSY	0.04
θ^{FMSY}_{West}	Western area fishing mortality rate at MSY	0.01
$\theta^{S}_{East\_stock,2017}$	Vulnerable biomass of the eastern stock in 2017	800 kt
$\theta^{S}_{West\_stock,2017}$	Vulnerable biomass of the western stock in 2017	50 kt
$\theta^{A}_{East,2017}$	Vulnerable biomass in the eastern area in 2017	730 kt
$\theta^{A}_{West,2017}$	Vulnerable biomass in the western area in 2017	120 kt
$\theta^{mix}_{West,East}$	Fraction of western stock in eastern area	0.1
$\theta^{mix}_{East,West}$	Fraction of eastern stock in western area	0.05
Harvest control rule		
α^{B}	The magnitude of the adjustment for biomass relative to BMSY	0 (no biomass adjustment)
β^{B}	Exponent parameter controlling extent of the adjustment for biomass relative to BMSY	NA (given α^{B} = 0)
α^{F}	Target fishing mortality rate (fraction of FMSY) at F/FMSY = 1 and B/BMSY =1	1
β^{F}	The magnitude of the adjustment for fishing rate relative to FMSY	0.5
Data smoothers		
ω	The ratio of the No. polynomial smoothing parameters to the number of years of time series data. I.e. loess(dat, enp.target = $\omega \cdot n_t$)	0.3
TAC adjustment limits		
θ^{up}	The maximum fraction that TAC can increase	0.1
θ^{down}	The maximum fraction that TAC can decrease	0.3
θ^{min}	The minimum fractional change in TAC	0.025
Index recalibration rule		
γ^{n}	The length of the time series for detecting slope of catches and indices	6
γ^{East}	The magnitude of F reduction in the East area in relation to the slope in Eastern stock biomass index	1
γ^{West}	The magnitude of F reduction in the West area in relation to the slope in Western stock biomass index	3

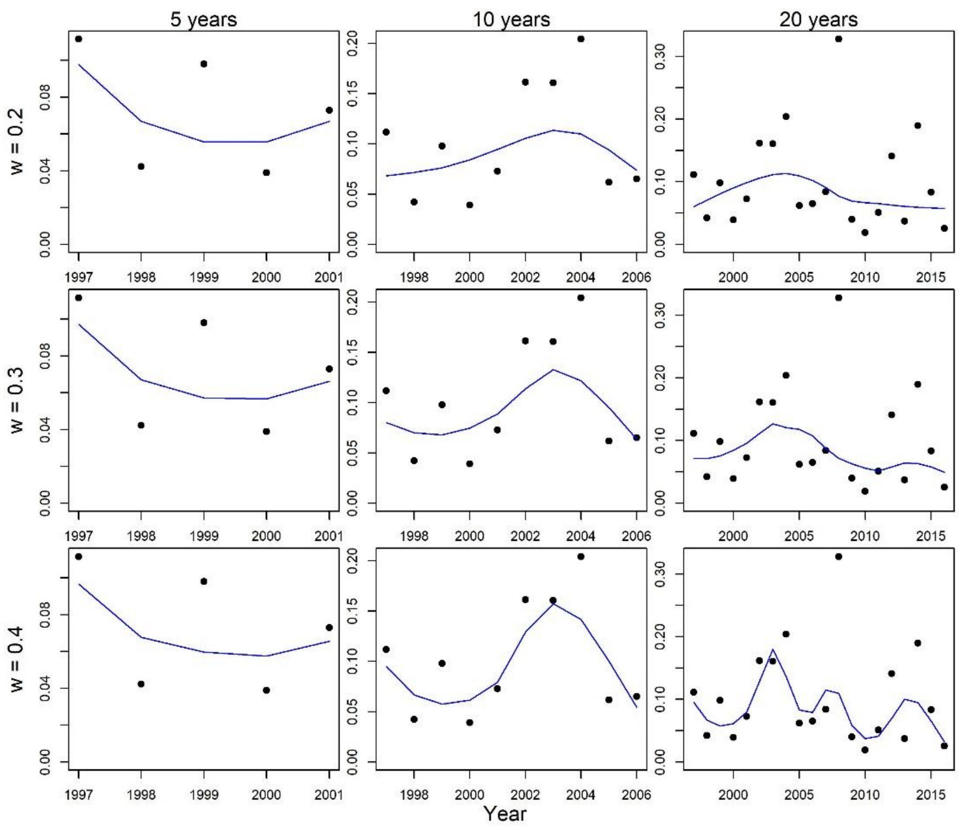

Figure 1. Effect of the smoothing parameter ω given time series of varying length.

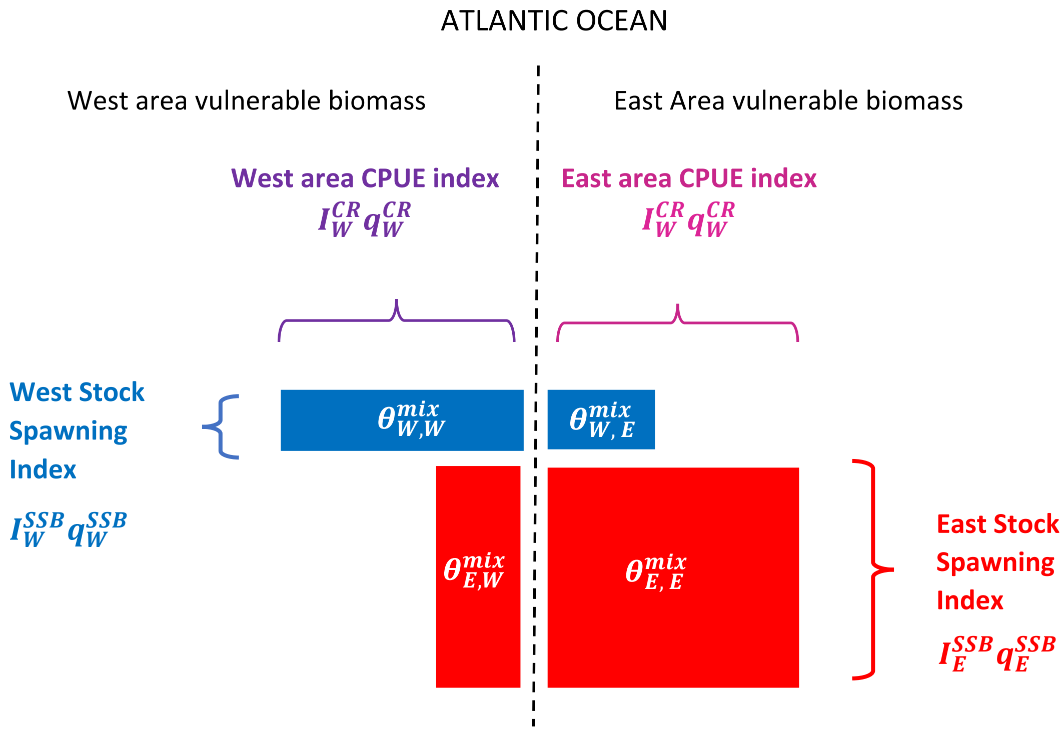

Figure 2. Regional vulnerable biomass estimation according to stock specific spawning indices and area-specific CPUE indices.

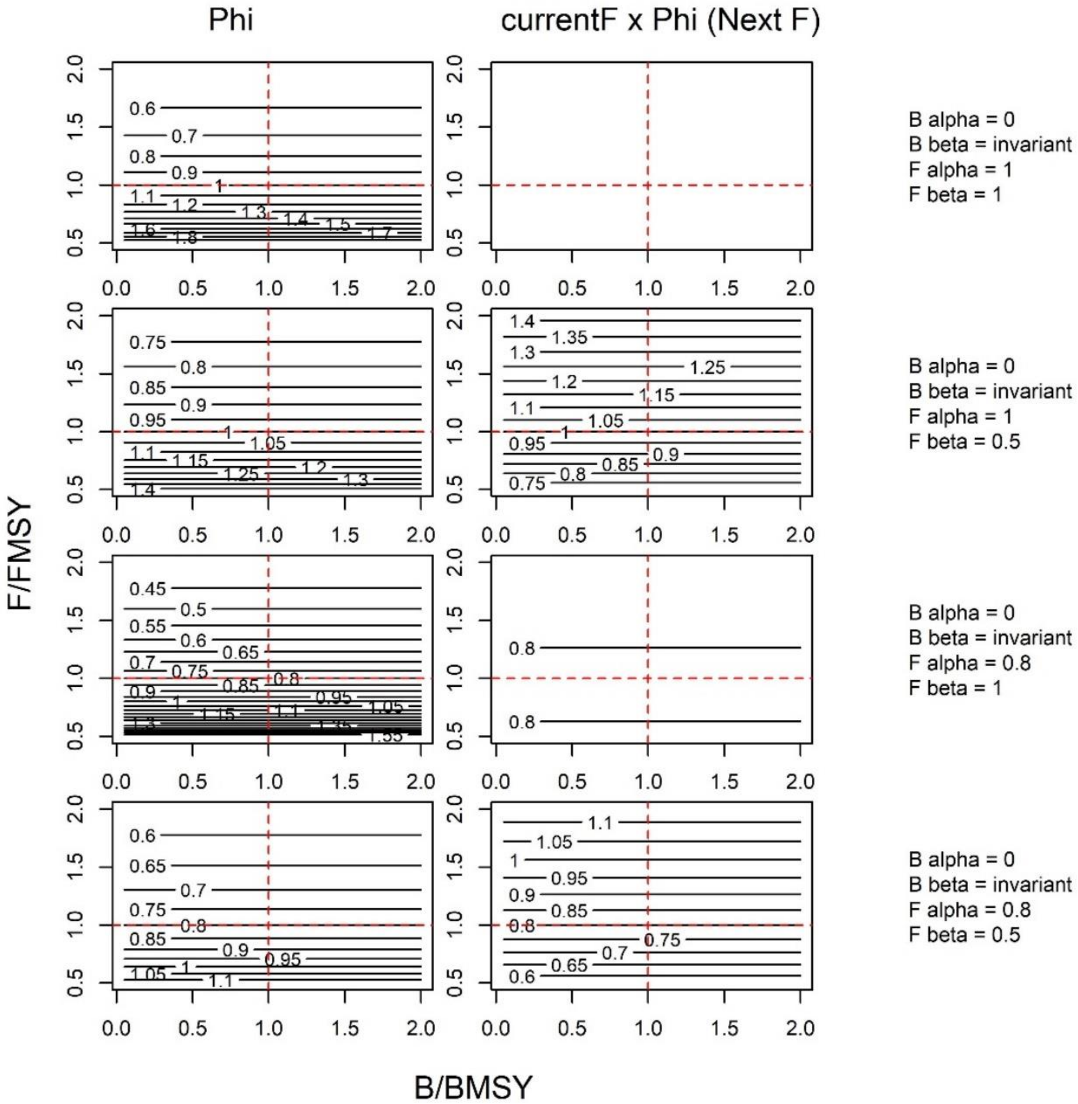

Figure 3. MP TAC adjustment based only on current fishing rate relative to FMSY ($\Delta^F_{a,t}$ only).

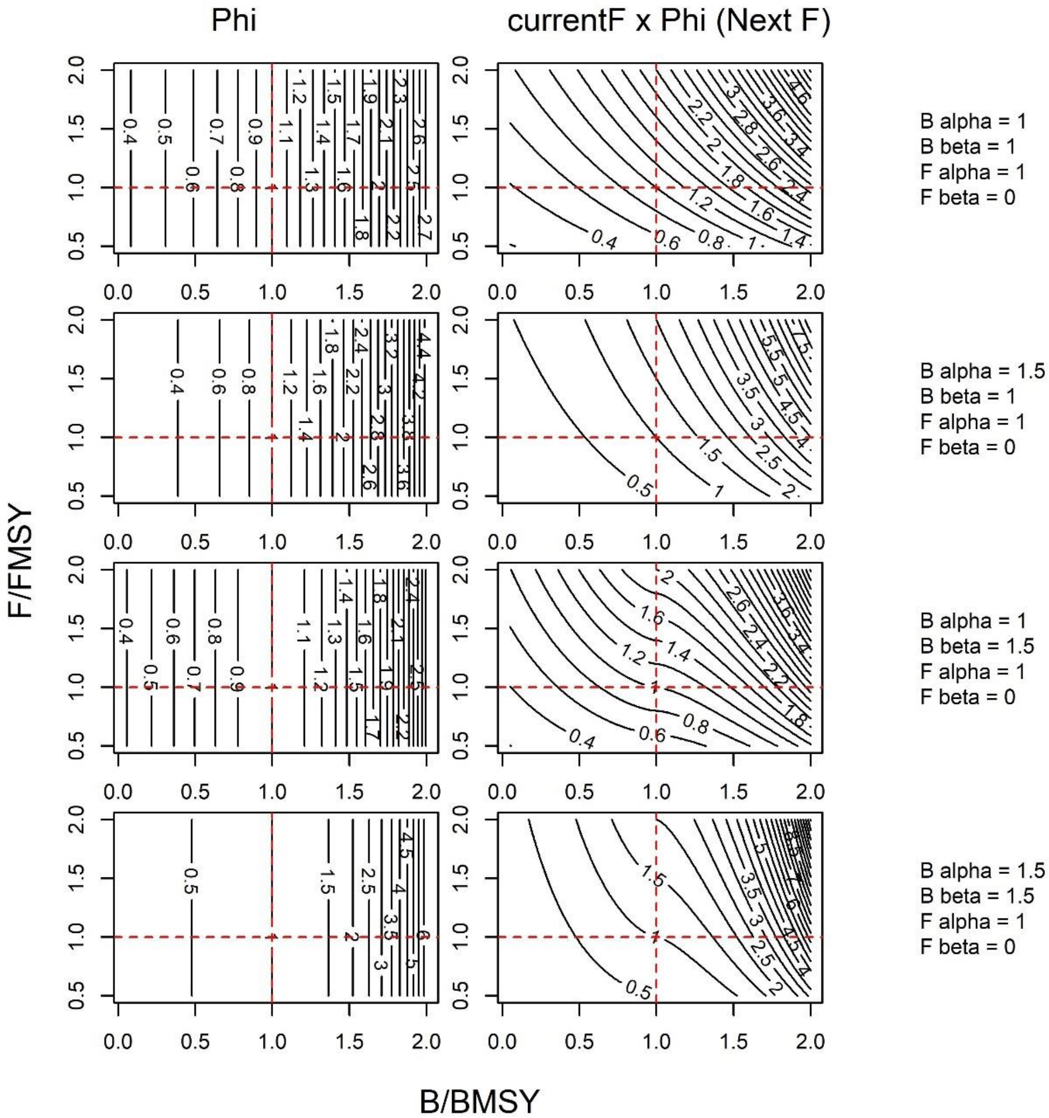

Figure 4. MP TAC adjustment based only on current biomass rate relative to BMSY ($\Delta_{a,t}^{B}$ only).

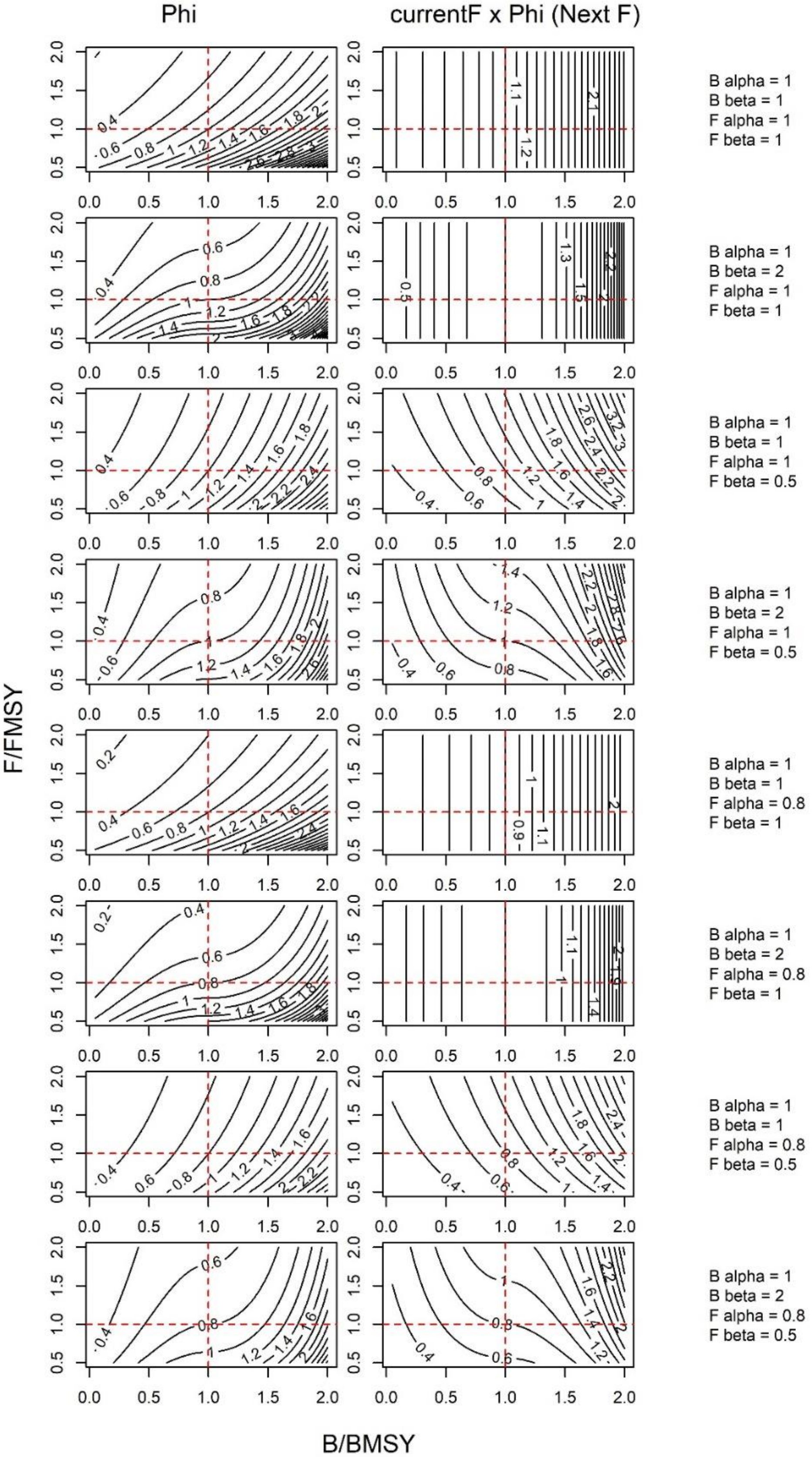

Figure 5. MP TAC adjustment using current estimates of biomass and fishing mortality rate relative to MSY levels ($\Delta^{B}_{a,t}$ and $\Delta^{B}_{a,t}$, respectively).