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A FISHERY-IMPACT-BASED MANAGEMENT REFERENCE LEVEL FOR PACIFIC BLUEFIN TUNA IN THE EASTERN PACIFIC OCEAN

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1. INTRODUCTION

Developing management reference points for Pacific bluefin tuna is problematic, due to sensitivity to the stock assessment model's assumptions. In particular, absolute levels of biomass and fishing mortality, and reference points based on maximum sustainable yield (MSY), are hypersensitive to the value of natural mortality (Aires-da-Silva *et al*. 2009; Ichinokawa *et al*. 2010; Kai *et al*. 2010). Relative trends in biomass and fishing mortality levels are more robust to model assumptions. Therefore, management reference points based on relative biomass or fishing mortality should be considered for managing Pacific bluefin tuna. It is unlikely that these management measures can be designed to optimize yield, and management should be designed to provide reasonable yields while ensuring sustainability until the uncertainty in the assessment is reduced.

Developing limit reference points based on historic levels of biomass, fishing mortality, or catch is common in data-limited situations. Essentially, the limit reference points are based on the assumption that if the biomass (or fishing mortality or catch) does not decline below (or increase above) the historic levels, the population should be sustainable because it was at those levels in the past. Historic catch limits are problematic because they do not take into consideration the current biomass compared to the biomass levels when the historic catch occurred. Historic biomass is also problematic because biomass can vary independently of fishing and biomass is not a management quantity that can be managed directly like catch and fishing mortality (effort). Fishing mortality is problematic because biomass levels are a function of multiple years of fishing mortality and the ages at which fish are caught, and these can change over time. Therefore, using the highest historical fishing mortality as a limit reference point would be inappropriate.

We develop a management "indicator" that is based on integrating multiple years of fishing mortality and takes the age structure of the fishing mortality into consideration. The indicator is based on calculationing the impact of fisheries on the stock of fish . We apply the indicator to Pacific bluefin tuna and evaluate its sensitivity to assumed levels of natural mortality (M).

2. METHODS

Maunder and Watters (2001) developed a simple approach to determine the impact of fishing on a fish population. The population is projected over a historic period with and without fishing, using a standard fisheries stock assessment model. The parameters of the model are fixed at values estimated using the stock assessment model with catch. The biomass level estimated without fishing minus the biomass estimated with fishing is an estimate of the impact of the fishery. Since the annual recruitments are the same in both scenarios, differences in biomass are due only to fishing. The use of estimated age-specific selectivity for the fisheries ensures that the ages of fish caught are taken into consideration. Finally, since the dynamics of the population is modeled over time, the difference in biomass is an accumulation of all catches before the year of interest. Maunder and Harley (2005) modified the method to allow the impacts to be attributed to different fisheries or groups of fisheries.

The impact of a fishery is calculated as follows (Wang *et al*. 2009):

1. Set the catch for all fisheries and the initial exploitation rate (used to generate the initial age-specific abundance, for 1952 in the case of Pacific bluefin tuna) parameters to zero. Simulate the dynamics from the estimated model parameters to estimate the dynamic (hypothetical) unexploited stock size (dynamic virgin spawning biomass, $S_{0,t}$).
2. Calculate the difference between the estimated spawning biomass (S_t) and $S_{0,t}$ to estimate the impact of all fisheries combined.
3. Set the catch for a given fishery (or group of fisheries) and the initial exploitation rate parameters for that fishery group to zero. Simulate the dynamics from the estimated model parameters to estimate the unexploited stock size in the absence of that fishery group.
4. Repeat Step 3 for each fishery group. The sum of the fishery impacts for the fishery groups will not equal the impact for all fisheries combined that was estimated in Step 2. Assign the impact from all fisheries combined to each fishery group by using the ratios of the impacts estimated in Step 3.

The fishery impact over time is used as an indicator for developing reference points based on historic performance. The assumption is that if the fishery impact is less than that seen in the past, then the population is likely to be sustainable at current levels of fishing mortality.

3. APPLICATION AND RESULTS

The fishery impact indicator is calculated for Pacific bluefin tuna based on spawning biomass. The fisheries are grouped into those in the eastern Pacific Ocean (EPO) and those in the western and central Pacific Ocean (WCPO) because setting management guidelines for the EPO is the goal of this analysis. The base case assessment developed by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) is used as the stock assessment model (Ichinokawa *et al*. 2010). The sensitivity of the fishery impact and its use as a management indicator to the different natural mortality assumptions (Table 1) are evaluated.

The index of impact proposed for management is calculated as the estimate of actual spawning biomass divided by the hypothetical spawning biomass in the absence of the respective fishery. This assumes that the impact is measured under the assumption that the impact of the other fisheries is not controlled. Alternatively, the impact could be the abundance without that fishery as a ratio of the abundance with no fishing (this alternative is not presented here).

The estimated impact of the fisheries on the Pacific bluefin population for the whole time period modeled (1952-2006) is substantial (Figure 1). The impact is highly sensitive to the assumed values for natural mortality. The WCPO fisheries have had a greater impact than the EPO fisheries, and their rate of increase in recent years is higher. The temporal trend in the impact is robust to the assumed level of natural mortality (Figure 2).

4. DISCUSSION

The temporal trend in the estimated fisheries impact is robust to the assumption about natural mortality.

Therefore, using the relative fishery impact as an indicator for management advice based on estimated historical performance may be useful. The impact of the EPO fisheries was substantially lower during 1994-2007 than it was during 1970-1993, when the stocks were depleted to a much lower relative size; however, the impact has been increasing recently (Figure 2). The average catch in the EPO fisheries during 1994-2007, the period of low fishery impact, is 4,221 metric tons (inter-quartile range 2,416-4,704 tons) (Figure 3). The estimated status of the stock is uncertain, and is sensitive to model assumptions. Catch levels should be set based on those years when the impact was low until the uncertainty in the assessment is reduced. This management measure should ensure that the fishery is sustainable as long as similar measures are taken in the WCPO.

TABLE 1. Values of age-specific natural mortality (*M*) used in the model. New *M* = *M* assumed in the current assessment (Ichinokawa *et al*. 2010); Old *M* = *M* assumed in the previous assessment (Anonymous 2008).
TABLA 1. Valores de mortalidad natural (*M*) por edad usados en el modelo. *M* nueva = *M* supuesta en la evaluación actual (Ichinokawa *et al*. 2010); *M* vieja = *M* supuesta en la evaluación previa (Anónimo 2008).

Age	**New *M***	**Old *M***
Edad	**M nueva**	**M vieja**
0	1.6	1.6
1	0.386	0.46
2	0.25	0.27
3	0.25	0.2
4	0.25	0.12
5	0.25	0.12
6	0.25	0.12
7	0.25	0.12
8	0.25	0.12
9	0.25	0.12
10	0.25	0.12
11	0.25	0.12
12	0.25	0.12
13	0.25	0.12
14	0.25	0.12
15	0.25	0.12
16	0.25	0.12
17	0.25	0.12
18	0.25	0.12
19	0.25	0.12
20	0.25	0.12

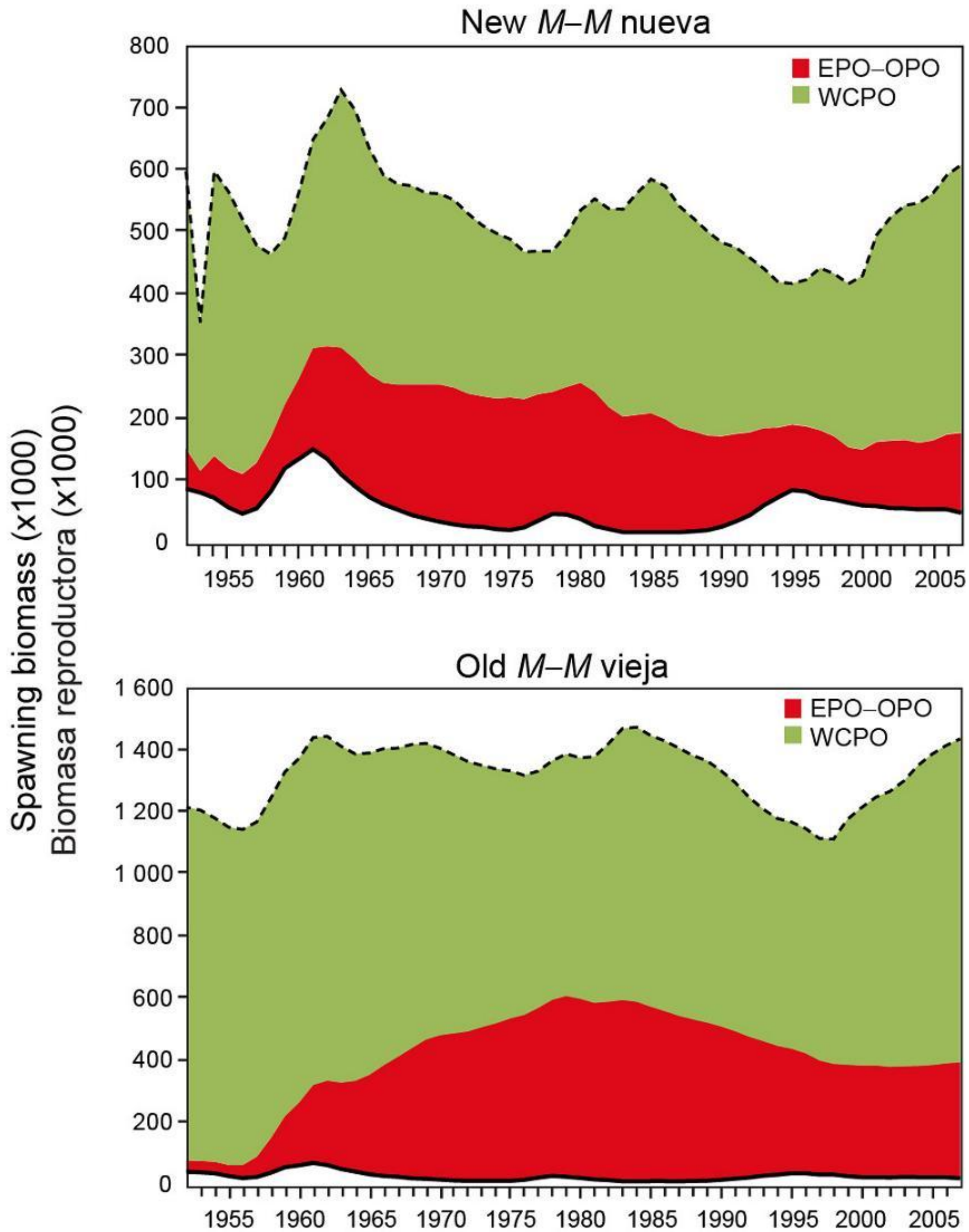

FIGURE 1. Estimates of the impact on the Pacific bluefin tuna population of fisheries in the EPO and in the WCPO for the new (upper panel) and old (lower panel) values of natural mortality (*M*). The dashed line represents the estimated hypothetical unfished spawning biomass, and the solid line the estimated actual spawning biomass. New *M* = *M* assumed in the current assessment (Ichinokawa *et al*. 2010); old *M* = *M* assumed in the previous assessment. The shaded areas indicate the impact attributed to each fishery.

FIGURA 1. Estimaciones del impacto sobre la población de atún aleta azul del Pacífico de las pesquerías en el OPO y en el WCPO correspondientes a los valores de mortalidad natural (*M*) nueva (panel superior) y vieja (panel inferior). La línea de trazos representa la biomasa reproductora no pescada hipotética estimada, y la línea sólida la biomasa reproductora real estimada. *M* nueva = *M* supuesta en la evaluación actual (Ichinokawa *et al*. 2010); *M* vieja = *M* supuesta en la evaluación previa. Las áreas sombreadas indican el impacto atribuido a cada pesquería.

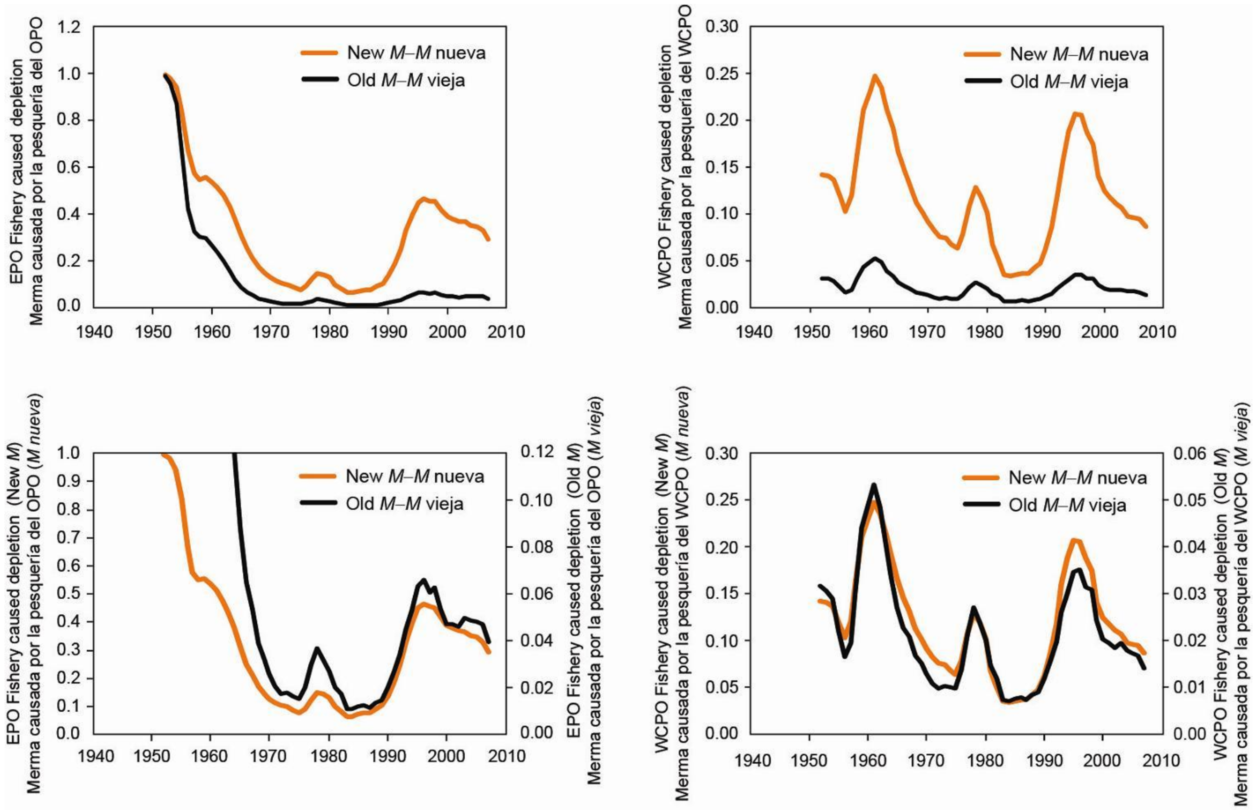

FIGURE 2. Stock depletion (actual abundance as a fraction of the hypothetical abundance if the fishery were not operating) caused by the EPO fisheries (left) and WCPO fisheries (right) for the new and old values of *M*, on the same scale (top) and on different scales (bottom). Higher values correspond to less depletion; *i.e.* actual abundance is closer to hypothetical abundance without the fishery operating.

FIGURA 2. Merma de la población (abundancia real como fracción de la abundancia hipotética si no operara la pesquería) causada por las pesquerías del OPO (izquierda) y WCPO (derecha) correspondientes a los valores nuevo y viejo de *M*, en la misma escala (arriba) y en escalas diferentes (abajo). Valores altos corresponden a menos merma; es decir, la abundancia real es más cercana a la abundancia hipotética sin la pesquería.

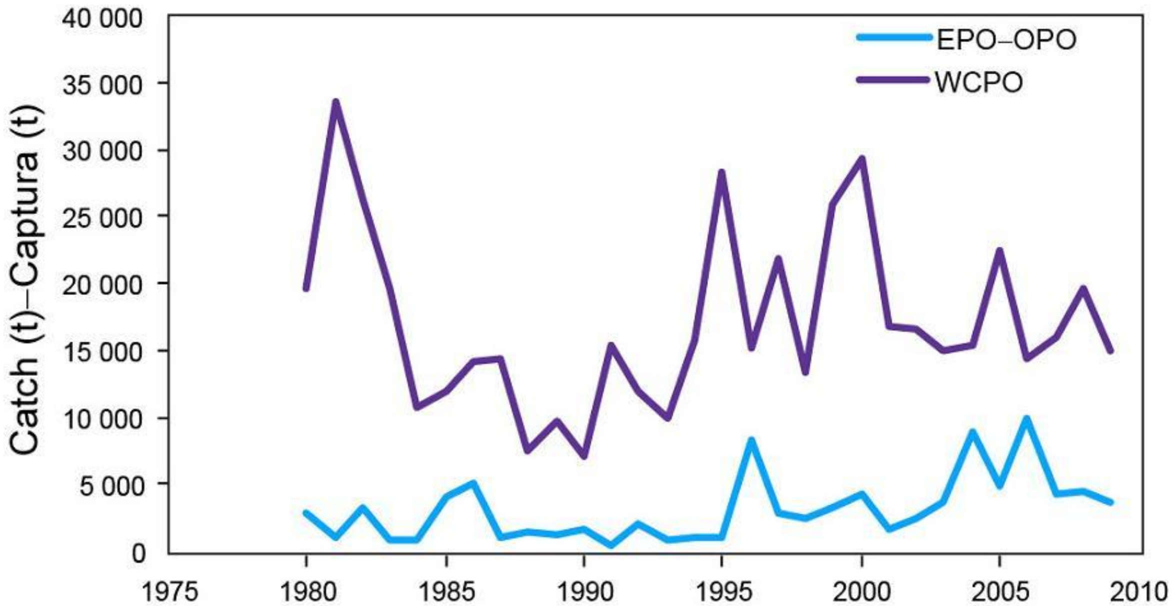

FIGURE 3. Total Pacific bluefin tuna catch in the EPO and WCPO, 1980-2009.
FIGURA 3. Captura total de atún aleta azul del Pacífico en el OPO y el WCPO, 1980-2009.

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