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# INCORPORATING CLIMATE CHANGE EFFECTS IN THE MANAGEMENT STRATEGY EVALUATION FOR ATLANTIC TROPICAL TUNAS

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*SUMMARY*

*Climate Change will impact fish and shellfish, their fisheries, and fishery-dependent communities through a complex suite of linked processes. In this document, we summarize the current practices to include climate information in management strategy evaluations (MSE), the available evidence regarding the potential impacts of Climate Change on tuna stocks, and the plan to implement the hypothetical impacts of Climate Change in the multi-stock MSE for tropical tunas in the Atlantic Ocean.*

*RESUME*

*Le changement climatique aura un impact sur les poissons et les crustacés, leurs pêcheries et les communautés qui en dépendent, par le biais d'une série complexe de processus liés. Dans ce document, nous résumons les pratiques actuelles visant à inclure des informations climatiques dans les évaluations des stratégies de gestion (MSE), les preuves disponibles concernant les impacts potentiels du changement climatique sur les stocks de thonidés, et le plan visant à mettre en œuvre les impacts hypothétiques du changement climatique dans la MSE multi-stocks pour les thonidés tropicaux dans l'océan Atlantique.*

*RESUMEN*

*El cambio climático afectará a los peces y mariscos, a sus pesquerías y a las comunidades dependientes de la pesca a través de un complejo conjunto de procesos relacionados entre sí. En este documento, se resumen las prácticas actuales para incluir información climática en las evaluaciones de estrategias de ordenación (MSE), las pruebas disponibles sobre los impactos potenciales del cambio climático en los stocks de túnidos, y el plan para implementar los impactos hipotéticos del cambio climático en la MSE multistock para túnidos tropicales en el océano Atlántico.*

*KEYWORDS*

*Climate Change, management strategy evaluation, tropical tunas, productivity, growth*

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## 1. Introduction

In this document, we summarize the current practices to include climate information in management strategy evaluations, the available evidence regarding the potential impacts of climate change on tuna stocks, and the plan to implement the hypothetical impacts of climate change in the multi-stock management strategy evaluation (MSE) for tropical tunas in the Atlantic Ocean.

## 2. Effects of climate in management strategy evaluations

### *2.1. Management strategy evaluations*

Management strategies are combinations of data collection schemes, stock assessment analyses applied to those data, and the harvest control rules used to determine management actions based on the results of those assessments (Butterworth, 2007). Management strategy evaluation is the evaluation of management strategies using a simulation framework and is the most accepted way to evaluate the trade-offs achieved by alternative management strategies and to assess the consequences of uncertainty for achieving management goals (Punt et al., 2016). An MSE is implemented following these steps:

a. Identification of the management objectives and their representation using a set of quantitative performance metrics
b. Development and parametrization of a set of alternative models of the system under consideration; each of these *operating* models provides an alternative plausible representation of reality, where the set is intended to capture the range of uncertainties that apply
c. Identification of alternative candidate management strategies that have the potential to achieve the management goals
d. Simulation of the future use of each candidate management strategy to manage the system as represented by each operating model under feedback control
e. Summary of the simulation results by performance measures

### *2.2. Climate impacts in management strategy evaluations*

Climate variation is recognized as a factor that needs to be included when evaluating management strategies. Climate change and environmental variation can act as drivers of a wide array of aspects of the population dynamics (e.g., spatial distribution, migration, spawning, diet, growth, recruitment, among others) that could be considered in MSEs. Punt et al. (2024) describe two ways to incorporate climate into management decisions: developing *climate-aware* harvest control rules or incorporating climate information in the operating model.

Climate-aware harvest control rules consist in relating environmental information to the target exploitation or reference points. However, this alternative is subject to the concern that relationships between environmental variables and population dynamics parameters may break down over time, and there is no strong evidence that they may outperform non-climate-aware alternatives. The most common ways to use environmental data in management strategies are (i) the dynamic $B_0$ approach (MacCall et al., 1985), (ii) the *moving window* approach, which calculates reference points based on the last $x$ years of biological parameters, (iii) the STARS approach, which is similar to the moving window approach but selects the recent period based on an algorithm and is particularly useful when modelling regimes. Szuwalski et al. (2023) explored the impacts of implementing *flexible* reference points (e.g., maximum sustainable yield, MSY) when climate regimes occur. They found that climate-adaptive management targets had a higher risk of stock depletion and had few benefits compared with the *status-quo* management. Bessell-Browne et al. (2024) found that the dynamic $B_0$ approach may be beneficial when combining it with a static $B_0$ reference point.

The second alternative is to use conventional harvest control rules (i.e., *status-quo*) but to use projections based on hypothetical impacts of climate variability on the stock. In order to do this, we could follow a mechanistic or empirical approach.

### 2.2.1. *Mechanistic approach*

Based on Punt et al. (2014), this approach involves:

i. Identifying mechanisms underlying the reproductive success, somatic growth, distribution of the stock, or other ecological aspects,
ii. assessing the feasibility of using climate scenarios derived from global climate models developed by the Intergovernmental Panel on Climate Change (IPCC) to select and estimate relevant environmental variables,
iii. evaluating the extent to which environmental variables from IPCC models reliably predict changes in the values of the biological parameters of the stock
iv. evaluating climate model scenarios and selecting IPCC models that appear to provide valid representations of forcing for the region of study,
v. extracting environmental variables from climate scenarios and incorporating them in projection models,
vi. conducting projections where future management actions are determined by the candidate management strategies for each IPCC model.

When using the mechanistic approach, there are two important sources of uncertainty that need to be incorporated into the MSE framework: how well environmental variables are able to forecast the biological process of interest (e.g., how strong is the relationship between temperature and the fish growth rate), as well as the consequences of different IPCC forecasts (Punt et al., 2014). Climate simulations have two main sources of uncertainty: structural uncertainty and uncertainty inherent in the climate system. The former arises because of assumptions made on key model processes, while the latter relates to the chaotic nature of the climate system. The recommended approach to incorporate these sources of uncertainty is to use multimodel ensembles.

### 2.2.2. *Empirical approach*

This approach allows for the impacts of climate change and environmental variation as well as ecosystem shifts by imposing trends in the values of some key parameters of the operating model that mimic plausible trends for those, without attempting to link the operating model explicitly to any type of climate model. This approach is appropriate when the impacts of the environment are postulated rather than supported by data. The main value of this approach is to explore the extent to which management strategies are likely to be robust to changing biological parameters (Punt et al., 2014). When using the empirical approach, the trend during the projection period is another source of uncertainty. For example, Bessell-Browne et al. (2024) explored three types of trends: cyclical, linear-to-nadir (i.e., a parameter linearly decreases until a certain value and then remains constant), and linear-to-zenith (i.e., a parameter linearly increases until a certain value and then remains constant).

## 3. Climate change and tunas

Using climate projections under a high-$CO_2$ emission scenario across all oceans, Erauskin-Extramiana et al. (2019) analysed the impacts of future marine conditions on the spatial distribution and relative abundance of six tuna species. They used spatial distribution models (SDMs) and catch and effort information from the Japanese longline fishery. An increase in the suitable habitat of tropical tuna species such as yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) is forecasted, especially in the Atlantic Ocean. Conversely, a warmer ocean will negatively impact the habitat of more temperate species such as bigeye (*Thunnus obesus*) and southern bluefin tuna (*Thunnus maccoyii*). Moreover, a spatial redistribution is projected: temperate tunas and bigeye are expected to decrease at low latitudes and expand their distribution limit poleward. These shifts will provoke a redistribution of global catches, with an increase in high-latitude regions and a decrease in the tropics (Cheung et al., 2010). Catches for tropical tunas, such as yellowfin and skipjack, are expected to increase in most of the tropical exclusive economic zones (EEZs). Also using SDMs and information from longline and purse seine fishery data, Chen et al. (2024) also project an increase in the suitable habitat of yellowfin and skipjack, but a decrease for bigeye in the Atlantic Ocean.

Erauskin-Extramiana et al. (2023) used a mechanistic model to investigate the future changes in productivity and body size of several tuna species worldwide under a low- and high-$CO_2$ emission scenarios. The authors modelled the fish life cycle and accounted for the effects of fishing, maintaining the levels around the MSY. They predict a decrease in global potential productivity by 36% and in body size by 15% by 2050. They also mention that adapting fisheries management strategies to these projected declines will be crucial to sustaining these stocks in the long term. For the case of tropical tunas in the Atlantic Ocean, the decrease in biomass will be similar among yellowfin, bigeye, and skipjack, while the decrease in body size will be less severe for yellowfin. However, also using a mechanistic model, Dueri et al. (2014) do not predict a decrease in body size for skipjack, but they do project a substantial decrease in its abundance and redistribution from tropical to template areas, especially during the second half of the current century. These studies produced contrasting results from those using SDMs, probably due to mechanistic models account for the population dynamics, life cycle, competition, prey biomass availability, and fishing, while SDM studies only focus on changes in the adult habitat suitability.

In the Pacific Ocean, Lehodey et al. (2013) used a mechanistic model and predicted a slight increase in skipjack in the Western Central Pacific Ocean until 2050, then a period of stabilization, and then a decrease after 2060. In addition, the authors project a redistribution of skipjack to higher latitudes and the eastern Pacific Ocean. Mislan et al. (2017) evaluated the impacts of future changes in oxygen concentration in the ocean on the vertical habitat of tunas. They found that bluefin tunas will be the most impacted species due to habitat compression, while resource partitioning is expected among tropical tunas in the northern subtropical and western tropical Pacific Ocean, the Arabian Sea, and the Bay of Bengal. Nicol et al. (2022) investigated the impacts of future ocean warming and acidification on yellowfin larvae in the Pacific Ocean. They predict a redistribution of yellowfin biomass in this ocean, and found that the effects of ocean acidification will be small in comparison to ocean warming but will have relevant impacts on spatial distribution.

## 4. Incorporating climate change in the multi-stock management strategy evaluation for Atlantic tropical tunas

Butterworth et al. (1996) recommended the following scheme to assign plausibility ranks to the hypothesis regarding the impacts of climate change in operating models:

a. how strong is the basis for the hypothesis in the data for the species or region under consideration;

Studies that examine the potential impacts of climate change are based on fishery-dependent historical observations, statistical models, and population or ecosystem models (mechanistic models). For the three tropical tuna species in the Atlantic Ocean, SDM studies predict an improvement of their suitable habitat of yellowfin and skipjack adults, and a reduction for bigeye. Conversely, mechanistic models that consider the fish life cycle and the effects of fishing predict a reduction in productivity and body size for the three tropical tunas. We consider that mechanistic models produce the best available projections for these stocks in this region.

b. how strong is the basis for the hypothesis in the data for a similar species or another region;

The projected impacts of climate change from SDMs and mechanistic models are generally consistent among oceans. Unlike other oceans, the body size of yellowfin and skipjack is projected to slightly increase in the Pacific Ocean.

c. how strong is the basis for the hypothesis for any species;

There is plenty of evidence that climate change will affect the dynamics of a wide range of fishes and their fisheries (Hollowed et al., 2013). These impacts may be positive or negative (Fulton, 2011; Lam et al., 2016; Moullec et al., 2019).

d. how strong or appropriate is the theoretical basis for the hypothesis?

The theoretical basis is well explored for some fishes, but less studied for tunas.

While some evidence exists of a negative impact of climate change on productivity and body size for tropical tunas in the Atlantic Ocean, there is still a need to conduct more studies to elucidate the mechanistic relationships between environmental variables and fish population dynamics. For this reason, for the multi-stock MSE, we will follow an empirical approach to evaluate the robustness of HCRs to the hypothetical changes of climate change on stock productivity and somatic growth in the operating model. This approach has been applied previously for tuna stocks. Merino et al. (2019) used an empirical approach to test the robustness of different HCRs to hypothetical changes in stock productivity and recruitment variability for North Atlantic Albacore. They mentioned that the impacts of climate change on this tuna stock is not well understood yet and aimed to explore the performance of management actions under potential changes in the future. Carruthers (2024) tested the robustness of HCRs to different hypotheses about the impacts of climate change on somatic growth, recruitment, survival, and condition factor for several large pelagic stocks.

To simulate changes in productivity, defined here as the number of fish that survive from eggs and larvae to become adults annually, we will vary the $R_0$ parameter during the projection period in two ways: a decreasing trend over the years and a regime shift from *status-quo* to low $R_0$. Likewise, to simulate changes in somatic growth, we will vary the $k$ (growth rate) and $L_\infty$ (asymptotic length) parameters simultaneously, which will have contrasting trends due to the negative correlation between them (i.e., faster growth rates relate to smaller asymptotic lengths). We will not test climate-adaptive reference points.

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