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Modeling the impacts of climate change on global tuna fisheries to support development and implementation of climate adaptive EAFM plans

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SUMMARY

The current paper summarizes (1) the work completed in 2018 as part of the FAO-implemented Common Oceans I Program, which focused on modeling the impacts of climate change on the productivity and distribution of tuna fisheries in the Pacific Ocean, and (2) the new work that is being proposed under the second phase of the Common Oceans Program. The primary objectives of the newly proposed work are to improve our current understanding of climate change impacts on global tuna resources by RFMOs and member states, and to increase global, regional and national commitment to development and implementation of climate adaptive EAFM plans for tuna fisheries. With the submission of this paper, we hope to receive feedback from IOTC on how best to proceed with projecting Climate Change impacts on global tuna fisheries using methods similar to those developed in the Pacific. We specifically wish to integrate the proposed activities into the normal scientific committee peer review processes at IOTC with the eventual aim of advising the Commission on potential actions needed to mitigate against adverse impacts.

KEYWORDS
Climate Change Impacts; Global Tuna Resources; Ecosystem Approach to Fisheries Management (EAFM)

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Introduction

Climate change is a significant threat to the long-term sustainable management of global tuna fisheries, but our understanding of the likely impacts is still preliminary and must be improved to reduce the risks posed by climate change to the long-term sustainable management of global tuna fisheries.

Preliminary analyses finalized in 2018 under the Common Oceans Program provide an initial assessment of the redistribution of tuna biomass in the Pacific Ocean under the ‘business as usual’ high emissions scenario (RCP8.5). This study relied on the application of the model SEAPODYM to each tuna species, first with a model parameterization phase over the historical period (1980-2010) using a reanalysis of ocean conditions, and then with projections of an ensemble of simulations to explore key sources of uncertainties. Five different atmospheric forcing datasets from Earth System models projected under the (“business as usual”) IPCC RCP8.5 emissions scenario were used to drive a coupled physical-biogeochemical model (NEMO-PISCES) first, and then SEAPODYM, over the 21st Century. Additional scenarios were included to explore uncertainty associated with future primary production and dissolved oxygen concentration, as well as possible adaptation through phenotypic plasticity of these tuna species to warmer spawning grounds. The impact of ocean acidification was also included for yellowfin tuna based on results from laboratory experiments. The historical simulations reflect key features of the ecology and behavior of the four tuna species and match the total historical catch in terms of both weight and size frequency distributions. The projections confirm previous results, showing an eastern shift in the biomass of skipjack and yellowfin tuna over time, with a large and increasing uncertainty for the second half of the century, especially for skipjack tuna. (Figure 1a).

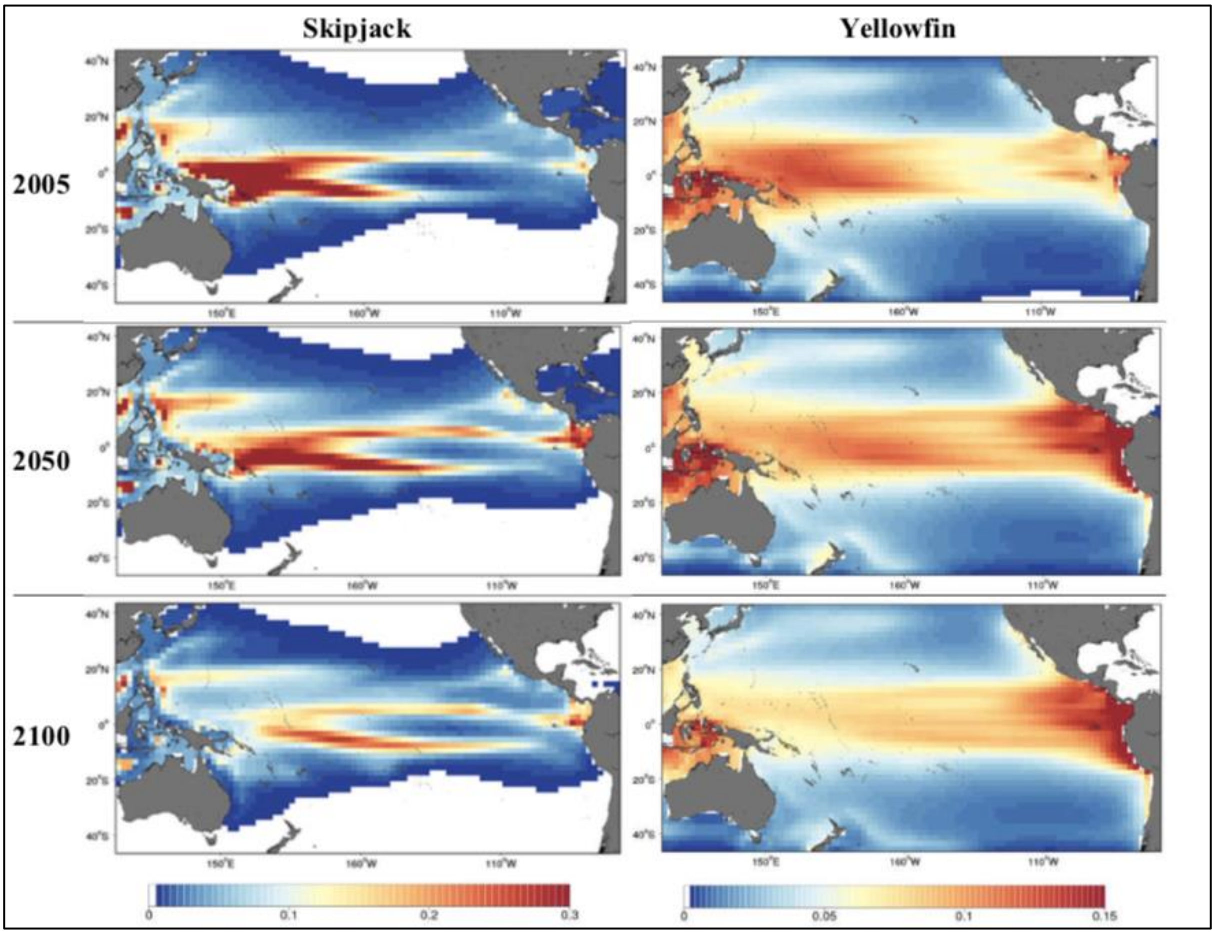

Figure 1a: Projected mean distributions of skipjack and yellowfin tuna biomass across the tropical Pacific Ocean under a high emissions scenario (IPCC AR8.5) for 2005 and from the simulation ensembles in the decades centered on 2045 and 2095 including projected average percentage changes for the outlined areas east and west of 150°W.

The impact is weaker for bigeye tuna and albacore due to revised parameter estimates, which predict a wider and warmer range of favorable spawning habitat (Figure 1b). For albacore, a strong sensitivity to sub-surface oxygen conditions resulted in a very large envelope of projections.

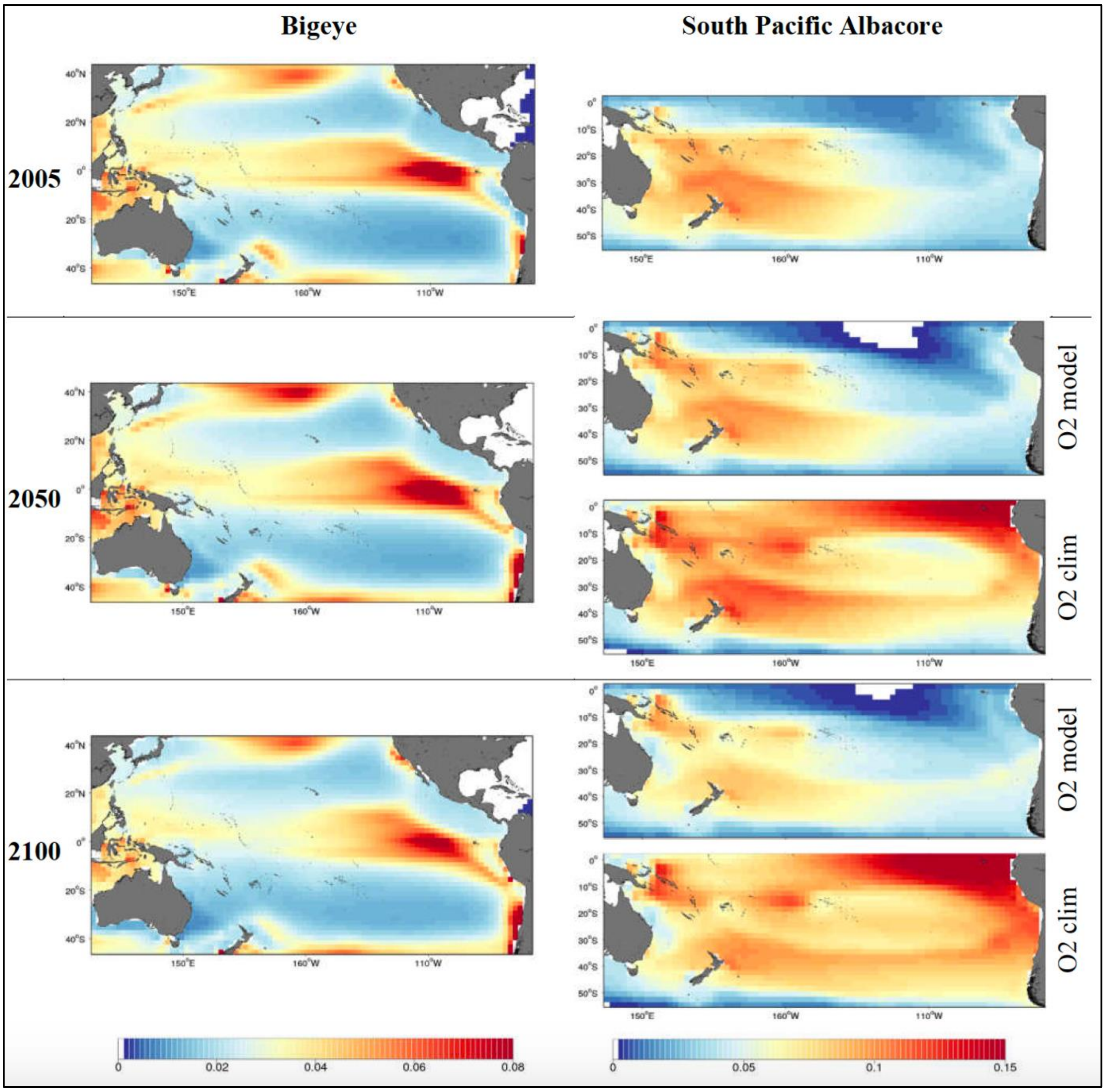

Figure 1b: Projected mean distributions of bigeye (left) and South Pacific albacore (right) tuna biomass across the tropical Pacific Ocean under a high emissions scenario (IPCC AR8.5) for 2005 and from the simulation ensembles in the decades centered on 2045 and 2095. For the South Pacific albacore two mean distributions are shown with and without the climatological oxygen scenario.

The study found that predicted climate-driven changes in (1) the biological productivity of tuna resources across the entire ocean basin, and (2) the relative biomass of tuna within the exclusive economic zone (EEZs) of small island developing states (SIDS) and in high-seas areas (international waters), pose significant challenges to the effective long-term management of tuna fisheries, and the vital contributions of tuna to national economies. The redistribution of Pacific tuna biomass as a result of warming sea-surface temperatures could cause significant economic hardship for tuna-dependent Pacific Island countries by 2050, including a total annual loss in fishing licence revenue across the region of at least $60 million (at today's prices) and losses of up to 15% in total government revenue each year.

Despite the fact that this modelling demonstrated the scope for significant changes in tuna biomass and the related socio-economic benefits to occur, key gaps in knowledge about the likely responses of Pacific tuna to climate change remain. For example, we do not have a comparable understanding of the likely responses of tuna biomass in the Pacific Ocean to the aspirational low emissions scenario (RCP2.6) because ocean forcings are not available for this scenario to inform modelling. In addition, the ocean forcings that are available to inform tuna modelling are at a course resolution (2º x 2º). Finer scale forcings are needed to more accurately and precisely project changes in tuna distributions and abundance within the boundaries on an EEZ, particularly for SIDS with relatively small EEZs. Furthermore, assessments of the impacts of climate change on tuna have been limited largely to the Pacific Ocean. Modelling is now needed for the other ocean basins where suitable catch data are available to validate the tuna-climate models.

The activities proposed in this concept note are specifically designed to improve our understanding of the potential impacts of climate change on tuna worldwide, to strengthen sustainable use of global tuna fisheries. Specifically, we propose to assemble the information needed to inform better models for the impacts of climate change on tuna fisheries in all major ocean basins and use this information to deliver improved models for tropical/subtropical tuna fisheries globally. This information will then be shared with the appropriate RFMOs and member states to enable them to make strategic investment/policy decisions to mitigate or adapt to the expected changes in tuna biomass. In particular, the outputs of this project will allow regional and national fisheries managers to incorporate the impacts of climate change in harvest strategies to sustain tuna catches.

We propose to:

1) Lay the foundation for improving models to assess the effects of climate change on tuna stocks in the Pacific, Indian and Atlantic Oceans by producing ocean variables for up to three greenhouse gas emissions scenarios (RCP8.5, 4.5 and 2.6 equivalents) by 2050 for the global oceans using atmospheric fields from 5 different Earth System Models to account for the uncertainty associated with individual models.
2) Incorporate these environmental variables to produce a forcing for SEAPODYM to model the likely responses of tuna to the changing ocean by 2050 for all tuna major fisheries where data are available to validate SEAPODYM.
3) Provide the projected changes in tuna biomass by 2050 to RFMOs to inform management measures to sustain tuna production under a changing climate.

Overall, the proposed activities will support effective management of global tuna fisheries through precautionary, ecosystem-based approaches designed to improve sustainability in areas within and beyond national jurisdictions, responding directly to GEF7 – IW Objective 2: "*Improve management in the Areas Beyond National Jurisdiction (ABNJ)*". Collectively, these outputs will equip fisheries managers to identify harvest strategies that reduce the risks to sustaining tuna catches posed by the effects of climate change on tuna and the ecosystem that supports these important fish species.

1. Technical Approach for newly proposed work

The core objective of the proposed project is to help ensure the sustainable management of global tuna resources as the world's oceans continue to warm. This objective will be achieved through the approach described below.

1.1 Development of new global ocean forcings to inform tuna modelling

The project team will work with expert oceanographers to develop ocean forcings (parameters quantifying expected changes to the main features of the ocean that determine the distribution and abundance of tuna) for the Pacific, Indian and Atlantic Oceans as input fields for SEAPODYM over the historical period 1979-2019 and projections until 2050. Historical simulations will be forced by ERA5. Projections will be based on three scenarios of emissions of radiatively active gases and aerosols used for CMIP6: (i) the 'business as usual', high-emission scenario (RCP8.5), a strong mitigation scenario (RCP2.6) for which emissions could lead to a global warming *likely* below 2°C above pre-industrial temperatures, in line with the aspirational target of the 2015 Paris Agreement, and an intermediate scenario (RCP4.5). For each scenario, an ensemble of 5 atmospheric forcings from Earth Systems Models (global climate models) will be used, corrected relatively to the historical reanalysis (ERA5) to avoid critical biases. These forcings will serve to run a coupled physical and biogeochemical model (NEMO-PISCES) at an improved resolution of 1° (grid ORCA1) compared to the previous study at 2° (ORCA2). The delivery of these forcings in due time is pivotal to the project:

- Month 6: Upgraded historical NEMO-PISCES hindcast (1979-2019) based on the ERA5 atmospheric forcing recently released by ECMWF on ORCA1 configuration, with an evaluation report
- Month 12: Corrected atmospheric forcings with report on the method, justification and validation of corrections

- Month 18: 1st ensemble of simulations 1° for three scenarios and one atmospheric forcing.
- Month 24: All remaining simulations at 1° with report on trends, variability and comparisons

1.2 Revising SEAPODYM to model the impacts of climate change on tuna stocks

The newly developed forcings for the global oceans will be used to model:

1. The impact on zooplankton and micronekton functional groups in the food web supporting tuna simulated with SEAPODYM and providing essential biological forcings for tuna dynamics modeling. This task includes preprocessing of environmental variables, simulations and validation of model outputs:
    - Month 7: hindcast (1979-2019) at 1° x month.
    - Month 20: 1st ensemble of simulations for three scenarios and one forcing.
    - Month 26: All simulations at 1°.

2. Revision of reference Maximum Likelihood Estimates (MLE) solutions for four tuna species in the Pacific Ocean, based on the new historical 1° simulation forced with ERA5 (1979-2019). This task will also include the preparations of geo-referenced fisheries datasets by species and basin, provided the necessary catch data are available, configuration of static parameters (growth, maturity), estimation of fisheries parameters and validation of the Pacific reference models in other basins.
    - Month 9: Skipjack (Pacific)
    - Month 11.5: Skipjack (Indian)
    - Month 14.5: Bigeye (Pacific)
    - Month 19.5: Bigeye (Indian and Atlantic)
    - Month 22.5: Yellowfin (Pacific)
    - Month 25 Yellowfin (Indian)
    - Month 28: Albacore (South Pacific)
    - Month 30.5: Albacore (Atlantic)

1.3 Estimating the impact of climate change on tuna stocks

1. Estimating model and projection uncertainties:

To provide the level of confidence for model predictions, this task will include the implementation of the approach to estimate model and projection uncertainties attributed to biases in physical and biochemical forcing variables and errors in estimation of model parameters and propagating through modelled mechanisms of fish population dynamics.

- Month 26: Estimation of uncertainty in Skipjack reference models
- Month 32: Estimation of uncertainty in Bigeye and Yellowfin reference models
- Month 38: Estimation of uncertainty in Albacore reference models

2. Ensemble simulations:

The impacts on Skipjack, Yellowfin, Bigeye and South Pacific albacore tuna in the Pacific Ocean basin at a resolution of 1º x 1º for the three emissions scenarios by 2050, and to model skipjack tuna at a finer spatial resolution based on available forcing. The finer spatial scale modelling for skipjack will quantify the benefits of such modelling for addressing the regions with complex bathymetry and oceanography as well as indicate the possible additional sources of uncertainty that need to be considered when projecting changes at the spatial scales of EEZs.

- Month 20: 1st ensemble 3 scenarios 1 forcing for Skipjack and Bigeye
- Month 33: All remaining 1° projections for Skipjack, Bigeye and Yellowfin with envelops of uncertainty for biomass predictions
- Month 39: All projections for Albacore with envelops of uncertainty

1.4 Dissemination of results, stakeholder engagement, and capacity-building

Key results will be presented to inform the following organizations in each ocean with responsibility for tropical tuna management about the implications of climate-driven tuna redistribution for sustainable tuna catches.

- Pacific: Pacific Islands Forum Fisheries Agency (FFA), the Parties to the Nauru Agreement (PNA), the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter American Tropical Tuna Commission (IATTC).
- Indian: Indian Ocean Tuna Commission (IOTC).

- Atlantic: International Commission for the Conservation of Atlantic Tunas (ICCAT)

In addition to RFMO meeting attendance by the project team, we also propose to publish working papers, policy briefs, news-articles, and peer-reviewed publications in order to widely socialize the project findings.

2. Next Steps

The proposed activities to improve the modelling of the expected responses of tuna to climate change across the world's oceans, and the associated activities to communicate the results to stakeholders, will equip governments and regional fisheries agencies to develop new fisheries management strategies that support climate-resilient tuna fisheries. The proposed investments will provide enduring benefits because the new ocean forcings and climate modelling will be available for RFMOs to integrate into the stock assessments that underpin harvest management strategies, until they are superseded by even more sophisticated modelling in the decades ahead.

At this stage, we welcome input from IOTC about the current proposal, particularly around co-developing an approach that would enable the most effective implementation of the proposed activities, including:

- Integrating the above workstream into the normal scientific committee peer review processes with the eventual aim of advising the Commission on potential actions needed to mitigate against adverse impacts.
- Capitalizing on synergies with on-going parallel work in the region, particularly through IOTC's Working Party on Ecosystems and Bycatch (WPEB)
- Leveraging the scheduled commission meetings in order to socialize project results as they become available.
- Assessing the availability of data that will be needed to develop the tuna re-distribution projections, including monthly spatially disaggregated catch data at resolution varying from 1 degree to 5 degrees squares.
- Identifying the best products that we could offer to member countries, particularly at the interface between modelling and decision-making.

For additional details about the methods used to develop the tuna re-distribution projections in the Pacific, which will guide the activities proposed under the new Common Oceans project, please refer to: Senina I. et al. (2018) Impact of climate change on tropical Pacific tuna and their fisheries in Pacific Islands waters and high seas areas. WCPFC-SC14-2018/EB-WP-01. Western and Central Pacific Fisheries Commission, Pohnpei

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