SCIENTIFIC COMMITTEE
NINETEENTH REGULAR SESSION

Koror, Palau
16 – 24 August 2023

POSEIDON, a Tool for the Exploration of Alternative Management Scenarios for Eastern Pacific Ocean Tropical Tuna Species

WCPFC-SC19-2023/MI-IP-09

IATTC Document SAC-14 INF-G[1]

[1] Inter-American Tropical Tuna Commission, Scientific Advisory Committee (SAC)

INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

14TH MEETING

La Jolla, California (USA)
15-19 May 2023

DOCUMENT SAC-14 INF-G

POSEIDON, A TOOL FOR THE EXPLORATION OF ALTERNATIVE MANAGEMENT SCENARIOS FOR EASTERN PACIFIC OCEAN TROPICAL TUNA SPECIES

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SUMMARY

- The Eastern Pacific Ocean (EPO) tropical tuna fishery includes bigeye tuna (BET), skipjack tuna (SKJ), and yellowfin tuna (YFT). It is a highly dynamic fishery with ever changing technology and the growing use of fish aggregating devices (FADs) since the early 90s. Species and fishers' spatial dynamics are strong drivers of this fishery.
- Scientists and fisheries managers have expressed an interest for a time- and cost-effective approach for the evaluation of alternative management scenarios across multiple species.
- The coupled agent-based bio-economic model, POSEIDON, was adapted to represent the EPO tropical tuna FAD fishery. It uses an adaptive behavior algorithm that is spatially explicit and inclusive of intra-species interactions. The adaptive nature of the agents allows for the evaluation of complex management scenarios while assessing social, biological, and economic tradeoffs.
- The POSEIDON – EPO tuna model integrates 5 modules to represents different aspects of the fishery including the environment, biology, FADs, fishing fleets, markets and management. This complexity of each module can be adapted to represent existing data.
- Through this collaborative work between the POSEIDON team and the IATTC staff, the POSEIDON application to the EPO tropical tuna fishery is expected to strengthen the set of tools available to the staff for the evaluation of the impact of alternative management scenarios.
- Likewise, the emergent behavior of the agents is expected to provide a reasonable approximation of key elements of the FAD fishery, including total landings, catch per action type, number of action types, timing of action types (FAD sets, unassociated sets, dolphin sets, and FAD deployments) within a trip, and other characteristics of the fishery.

1. POSEIDON-EPO TUNA MODEL CONFIGURATION

POSEIDON is a coupled agent-based bio-economic model (ABM) that simulates fishery vessel behaviors and evaluates the impacts of social, biological, and economic effects on the system (*Bailey et al., 2019*). It rapidly evaluates the performance of fishery management scenarios and associated tradeoffs against desired objectives by coupling traditional policy and marine biology modeling layers with an adaptive agent-based layer of fishing vessels. The use of individual agents can depict the heterogeneous responses of fishers in the system *(Carrella et al. 2020)*.

The POSEIDON framework is being adapted to represent the EPO tropical tuna fishery to achieve the following goals 1) Assess the performance (economic and biological) of alternative management scenarios for the sustainability of tropical tuna purse seine fisheries in the Eastern Pacific Ocean (EPO). 2) Expanding tools and enhancing scientific staff efficiency by automating routine evaluation of alternative management scenarios; and 3) Expand analytical capabilities related to the management of fish aggregating devices (FADs).

The POSEIDON-EPO tuna model consists of six modules that represent different aspects of the purse seine fishery (Figure 1). The modeling domain spans the entire EPO region for the tropical tuna fisheries and represents BET, SKJ, and YFT. Fleet data were input to establish the spatial configuration of the model and information such as port location, vessel properties, time at port, operating costs, and fish prices were used to initialize the model for class 6 purse seine vessels. Additional sources of catch and mortality from class 1-5 purse seine and longline vessels were included as exogenous factors in the model and their behaviors were not modeled explicitly. Supplemental information on the different components of POSEIDON is provided in Section VI.

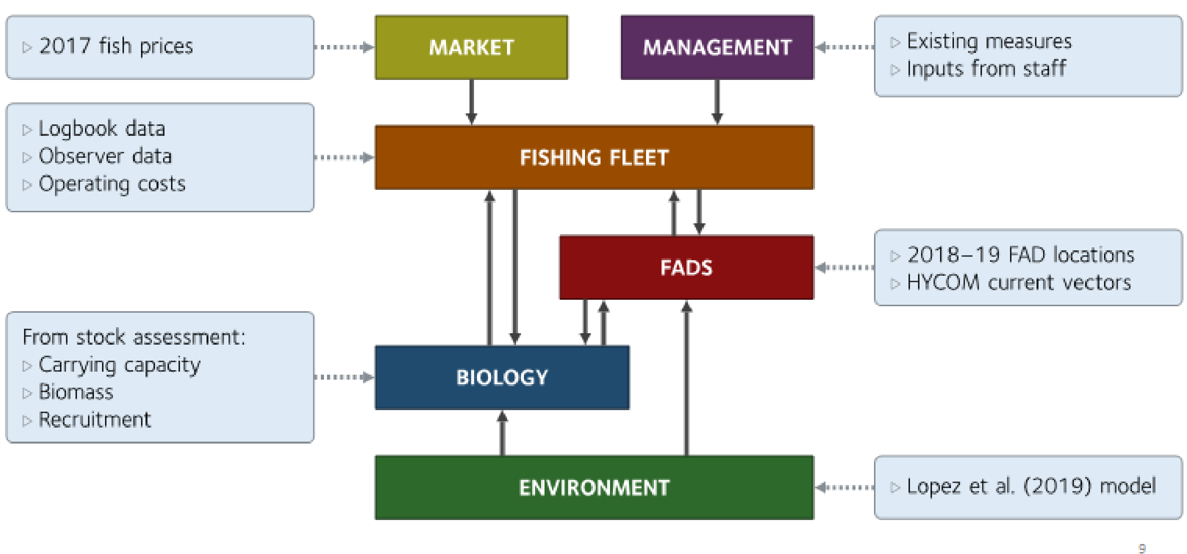

FIGURE 1. Schematic diagram of the six POSEIDON-EPO tuna modules and some examples of the data used to inform them*.*

2. POSEIDON-EPO TUNA AS A TOOL TO EVALUATE ALTERNATIVE MANAGEMENT SCENARIOS

POSEIDON-EPO tuna was designed to assess the socio-economic and biological performance of management scenarios for the sustainability of EPO tropical tuna purse seine fisheries. The emergent behavior of the fishing agents can also help to identify unintended consequences of management interventions, such as changes in fishing strategy or location.

The IATTC staff and POSEIDON-EPO tuna model researchers hope that the model will be able to explore the following management scenarios:

- Spatial closures
- Temporal closures
- Catch limits (Global or Individual Vessel Limits)
- FAD limits

For illustration purposes, a hypothetical management scenario from the list above was implemented to test the elasticity of the model to management intervention. The number of active FADs was reduced from current levels (100%) to zero at various intervals. The analysis comprised 448 simulations and was complete in 70 minutes. In the global sense both the total and average catch remained near the 100% FAD limit levels until the percentage of active FADs was reduced to <30% of current active FADs. Below 30% of current FAD limits, FAD fishers modified their fishing strategy and slightly increased the number of dolphin sets. This change in strategy is also reflected in the operating costs (Figure 2). While the results of this sensitivity analysis are exploratory we don't have a full evaluation of the efficacy of this approach, the POSEIDON – EPO tuna model is producing interesting output qualities of interest based on the underlying data and assumptions. If proven to be effective the POSEIDON-EPO tuna model could be used to evaluate FAD management scenarios, assess bio-economic tradeoffs, and capture the adaptive nature of the fishery.

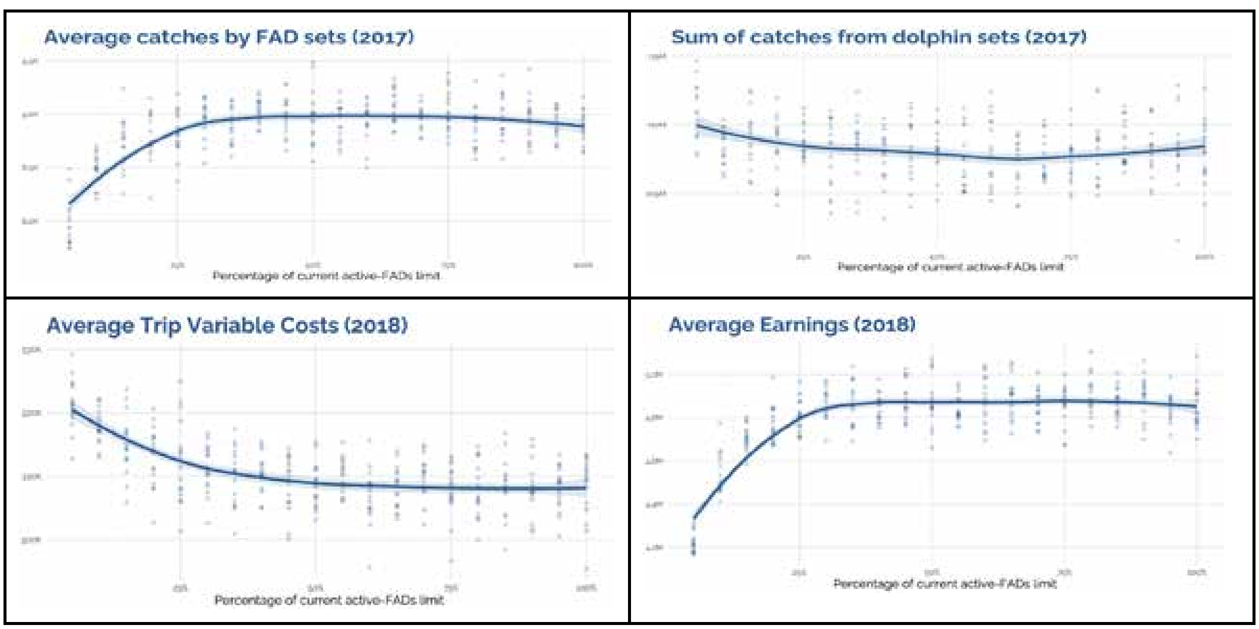

FIGURE 2. Results of the analysis exploring the effects of different active FAD limits over a range of 100% of current day to zero at various intervals. a) Average catches by FAD sets (2017), b) Sum of catches from dolphin sets (2017), c) Average trip variable costs (2018), and d) Average earnings (2018).

3. NEXT STEPS

The POSEIDON-EPO tuna model researchers and IATTC staff have identified the following tasks to occur in 2023-2024:

- Improve the spatial match of observed and modeled FAD fishing effort;
- Develop detailed model documentation;
- Implement a supply chain model to explore exogenous price shocks;
- Further understand model sensitivity and robustness of management advice generated; and
- Increase usability of the model through an R programming language package and trainings for IATTC staff.

4. ACKNOWLEDGEMENT

In addition to the authors listed, we are grateful for the contributions of the following individuals who supported the development of the POSEIDON-EPO tuna model. We thank the fishers and the following companies for contributing their knowledge: Ugavi, Nirsa, Atunera Dullarra, Delipesca and Albacora. From ISSF, Victor Estrepo; from AZTI, Jefferson Murua; from the FAD Advisory Group: Laurent Dagorn, Manuela Capello, Joe Scutt Phillips, Laurianne Escalle, Josu Santiago; and from the Economic Advisory Group: Patrice Guillotreau, Elizabeth Havice, Liam Campling, Santiago Buccaram; and from ATUNA, Giacinto Bottone. This work was supported by the Gordon and Betty Moore Foundation (Grant #4850.02).

5. SUPPLEMENTAL INFORMATION ON MODEL CONFIGURATION

Biology and Environment

An age-structured biological model for BET, SKJ, YFT was implemented using the most recent stock assessment information, which included 2018 assessments for YFT and BET (Xu, 2018; Minte-Vera, 2018).SKJ biology was informed by Hoyle (2010) and Schaefer and Fuller (2019). Tuna biomass was further spatialized using boosted regression tree species distribution models to predict relative habitability maps for adult and juvenile tuna following the methods of Lopez *et al*. (2019).

FADs

Vessels adaptively deploy FADs into 1 x 1 degree ocean cells based on historical deployment locations. A statistical FAD drift model was implemented in POSEIDON-EPO tuna which allows for a faster computation model than Langrangian methods. A 24-hour bilinear interpolation drift model was developed by comparing a series of drift models over the start and stop location of seven experimental samples of anonymized buoy data over a 30- and 90- day period (Powers *et al.*, in progress) against hourly HYCOM (Metzger *et al.*, 2017) velocity vectors.

Aggregation of fish around the FADs is a linear function of the abundance of the fish in the cell occupied by the FAD. The amount of fish aggregated by the FAD is further affected by age and sex selectivity, and environmental factors such as sea surface? temperature. Each FAD releases fish according to a calibrated daily hazard rate applied randomly to each FAD. The carrying capacities of the FADs are drawn from Weibull distributions whose shape values are determined through calibration. Aggregation rates, or the rate at which tuna are aggregated to a FAD occupying an ocean cell, for all three species are also calibrated terms.

Fisher Behavior

Fisher behavior within the model is driven by a planning strategy in which fishers try to establish which actions they intend to execute in which locations. The choice of these actions is conditioned by historical (2017) preferences of the fishers, derived from the observer database.

A number of behavioral algorithms were assessed that use different perceived value metrics on where agents target their effort. The current best fitting behavioral model uses a Value Per Set (VPS) destination strategy as part of a path-planning algorithm to plan a trip. The VPS algorithm computes the average value per set in a localized area by computing the total amount of expected revenue of fish under the FADs divided by the number of FADs in that area, resulting in the average value per set of that ocean cell. The path-planning algorithm then uses the VPS algorithm to plan and revise a fishing route on regular intervals until the hold is full and the vessel returns to port.

Economics

Vessels incur daily operating costs that vary with vessel size and are inferred from Anastacio and Bucaram (2017. Annual price per ton for each of the three species is used to estimate expected revenue and profits for each FAD. A supply chain model is currently under development which will allow for testing the impacts of changes to the global supply chains and prices on the EPO tropical tuna fishery.

Calibration and Diagnostics

Most simulation parameters are empirical, including those related to vessel characteristics, time at port between trips, and maximum catch under the FADs. The remaining parameters, referred to as free parameters because they are unknown, were estimated. There are currently 15 FAD-related and 13 fisher behavior-related free parameters. These generally inform the FAD aggregation rate or intervene in the individual choices the fishing agents make, such as the frequency at which fishers update their fishing plan.

The following calibration process was used to estimate free parameters. First, plausible ranges for all free parameters were identified. Second, calibration targets using values that are known from the empirical data were identified. Lastly, a search algorithm (Streicher 2005) was used to explore the space of free parameters and identify a combination that produced values as close as possible to the calibration targets when running the simulation.

The model was calibrated against 2017 observer data. This is the most recent year with a complete dataset at the start of the project. Targets used for calibration included total landings, timing and number of actions, trip durations, setting on own versus other FADs, and dolphin settings.

The resulting model was able to fit targets for the entire EPO such as the number of FAD actions (own FADs, others FADs, unassociated sets, FAD deployments, and dolphin sets), catches of all three species (own FADs, others FADs, unassociated, and dolphin sets), total catches (BET, SKJ, YFT), trip duration, and average hours out from observer data with low (<10%) error (Figure 3). Spatial fishing patterns and timing were realistic. However, FAD fishing effort north of the equator and on the western boundary of the EPO area tended to be underestimated. Additionally, the model was able to capture the patterns of deployment and FAD set regions for each of the fishing fleet clusters identified by Lennert-Cody (2018), indicating the model is able to capture the various fishing strategies of the fleet (Figure 4).

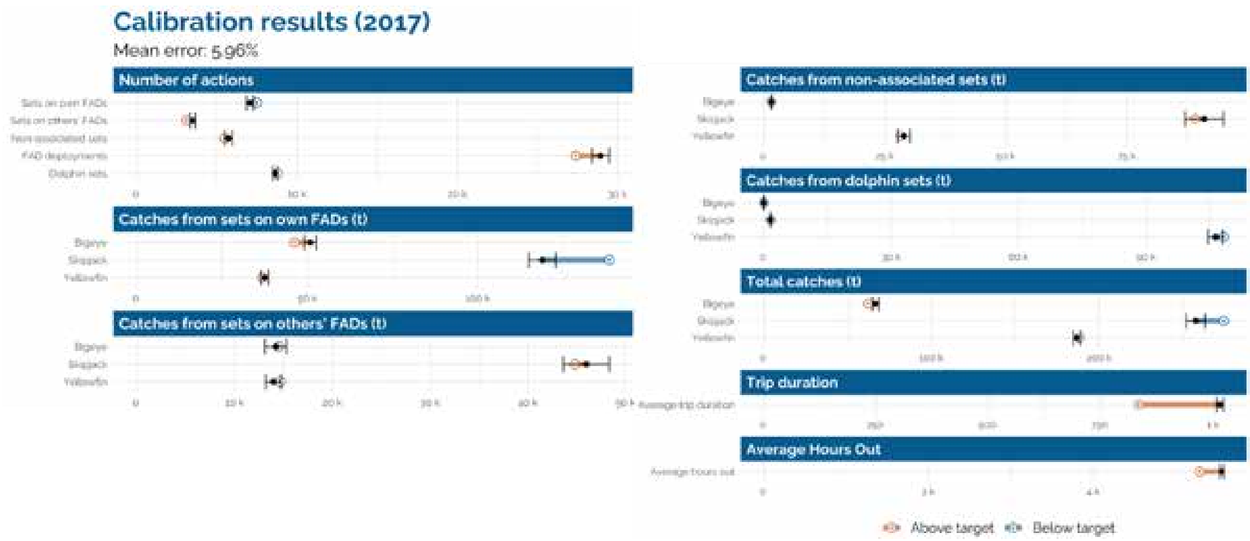

FIGURE 3. Calibration results of the most recent POSEIDON-EPO tuna model resulting in an overall mean calibration error of 6%. For each calibration target, the bullseye represents the target value derived from observer data and the black point and range represent the calibration model outcomes.

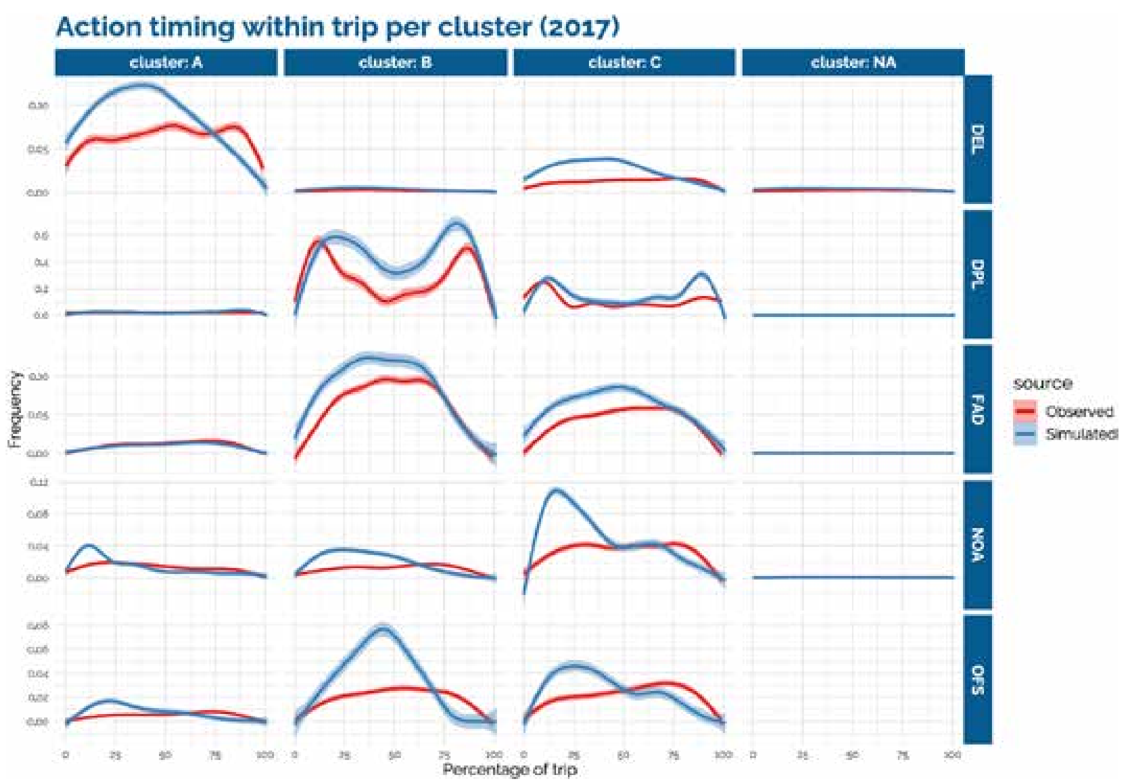

FIGURE 4. Comparison of observed and modeled timing of FAD fishing actions (dolphin (DEL), deployment (DPL), FAD set, unassociated set (NOA), and set on others FADs (OFS)) for each of the vessel cluster types identified by Lennert-Cody (2018). Trip duration is standardized as a percentage of total trip length as individual trips will have different total durations.

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