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Progress report on development of a spatially explicit operating model for tropical tuna populations.

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Executive summary

We present planning for and progress towards the development of a spatially explicit population model of yellowfin tuna in the Indian Ocean. SPM (Spatial Population Model) is software that captures the dynamics of spatial heterogeneity of a population along with age structure, movement and reproductive stage transition in a holistic framework. Using this software, spatially explicit age-structured models will be developed for the yellowfin tuna (*Thunnus albacares*) population in the Indian Ocean and used as operating models to evaluate the performance of stock assessments. The models will be generalised Bayesian population models, optimised by fitting to fishery observations. Movement is parameterised using preference functions based on spatially discrete environmental layers. The shapes of the preference functions will be established through iterative model testing with the parameters defining the preference functions estimated within each model. The spatial structure of the models divides the Indian Ocean region into five-degree cells. The underlying spatial distribution of the population was either restricted to the western tropical area, or to the entire Indian Ocean. Estimates of movement rates will be compared with the results of tagging studies, and fits to the other observations explored (size, CPUE, reproductive development). These operating models will then be used to investigate potential biases of the current Stock Synthesis assessment.

1 Introduction

The Indian Ocean Tuna Commission (IOTC) is mandated to manage 16 species of tuna and tuna-like species with its primary objective the conservation and optimum utilization of the stocks for long-term sustainability. Tropical tuna (yellowfin tuna, skipjack tuna, and bigeye tuna) have accounted for approximately 55% of total catches of all IOTC species in recent years and are of major commercial importance to Indian Ocean coastal states as well as distant water fishing nations.

Management advice for tropical tuna species is based on integrated assessment models that accommodate complex population processes and a diverse range of data. To date there has been limited effort within the IOTC scientific community to comprehensively investigate the considerable uncertainties in the tropical tuna population dynamics. In particular, movement dynamics and population structure are poorly understood but may have an important influence on assessment results.

Tropical tuna assessments have integrated the tagging data to inform population size and movement dynamics and these data are highly influential for estimates of stock levels and reference quantities (Fu and Fiorellato 2017; Langley 2015; Langley 2016). The assessments depend on the assumption that tagged and untagged fish have the same probability of recapture. Violation of the assumption of homogeneous mixing of tagged fish at the relevant spatial scale, possibly due to non-random fish movement or distribution of fishing effort, is likely to introduce bias into the estimation of fish abundance and other management quantities.

Spatially explicit assessment models have indicated that the mixing rates of the populations were probably low at the ocean-basin scale for all tropical tuna species. Most tags collected from the Indian Ocean Tuna Tagging Programme (IOTTP) were released in the local area, and tag recoveries were influenced by the spatial distribution of the catch from the fisheries and variable reporting rates amongst fleet. Langley and Million (2012) found that the tag recoveries of yellowfin from the FAD purse-seine fishery were not adequately mixed during the 6-month period when their size matched the main selectivity ogive for FADs. However free-school tag recoveries of larger fish indicate a higher degree of mixing within the fished population. Examination of the tag recoveries of bigeye from the PSLS fishery identified considerable differences in the recovery rate amongst latitudinal zones for tags at liberty for at least 12 months (Langley 2016). The low connectivity of skipjack tuna between the East and West Indian Ocean, as evident in the tagging data, could also be attributed to the apparent differences in reporting rate amongst fleet and tagging programs (Fu and Fiorellato 2017). Using different methods, Kolody and Hoyle (2014; 2013) identified incomplete mixing for Indian Ocean skipjack for at least 3 quarters following release, and in the Western and Central Pacific Ocean (where tagging programs and fisheries were structured differently, and there are more data) for at least 6 quarters after release.

Regional partitioning of sub-populations with different tag dispersion rates, and the discounting of observations during the “non-mixing” period serves to reduce the bias caused by spatial heterogeneity. However, to fully quantify the extent of the bias requires a good understanding of the underlying drivers of tuna migration and movement. Simulation experiments using spatial movement models can provide a useful tool to evaluate the direction and magnitude of potential bias and uncertainty caused by non-random distribution of tags and/or fishing effort in the context of area-aggregated or spatially explicit stock assessments.

Dunn and Rasmussen (2008) developed a generalised spatially explicit statistical catch-at-age population modelling tool (SPM), with improved observational and statistical methods for estimating and modelling the movement dynamics of fish populations, particularly at finer spatial scales. SPM (Dunn and others 2012) allows for a wide range of spatial models to be implemented in a timely and efficient manner. Mormede and others (2014) applied this model to Antarctic toothfish in the Ross Sea region and demonstrated how simulated observations from the spatial operating models could be used to evaluate performance of the assessment.

The aim of this project is to use a similar approach to develop a spatially explicit operating model for the tropical tuna population, to evaluate potential assessment bias possibly due to the violation of the assumption of homogeneous mixing of tag and untagged fish, and to improve the understanding of the underlying drivers of movement dynamics for these highly migratory species.

2 Methods

We will develop a spatially explicit age-structured population dynamics operating model for yellowfin tuna in the Indian Ocean. The model will be developed as a generalised Bayesian population dynamics model implemented using the Spatial Population Model software (Dunn and others 2012), and a single sex age-structured model that categorises all fish as juvenile or adult.

The model will comprise the following components: (i) the dynamics of the fish population; (ii) the fishery dynamics; (iii) the dynamics of tagged fish; (iv) observation model for the data; (v) parameter estimation. The model will incorporate population processes (recruitment, growth, maturity, spawning, movement, natural and fishing mortality, etc.) at relevant spatial and temporal scale in accordance with biological and fishery characteristics of the species. The spatial extent of the operating model will encompass the plausible habitat of tropical tuna, including both fish and unfished areas. The spatial structure will include spatial cells based on 5 by 5 longitude and latitude. Alternative structures will also be considered when necessary to explore different spatial scales.

The operating model will use a range of spatially-explicit observations, including commercial catch, standardised CPUE indices, length frequency, and tagging data to estimate population and movement parameters. The operating model will implement movement dynamics within an appropriate spatial structure. Movement will be modelled using preference functions based on spatially discrete environmental layers (e.g., surface temperature, currents, chlorophyll, oxygen concentrations, etc). Population and movement process parameters will be estimated using a maximum likelihood or Bayesian approach, accounting for statistical, observational, and process errors. Where appropriate, a broad range of model configurations will be explored to account for structural uncertainty.

To use the model to simulate data sets for evaluating assessment bias, we will generate pseudo-observations from the operating model. Replicates of random observations including CPUE, length frequencies, tag-releases, and tag-recaptures will be simulated. Each observation will be simulated assuming appropriate error distributions, and structural uncertainty may be accounted for from a range of alterative but plausible model configurations.

Simulated observations will be incorporated into the tropical tuna assessment model to estimate stock size and other parameters. The potential bias will be evaluated by comparing the stock assessment model estimates using pseudo-observations with the value used by the operating model to simulate those observations, assuming that the operating model represents the underlying true fish population. The estimation model will maintain consistency with formal stock assessments, with possible variations to incorporate revisions from the Scientific Committee and its subsidiary bodies. The comparison will focus on estimates of key management quantities including initial and current biomass levels, MSY, and BMSY. The percent bias (%bias) and the root mean squared error (%RMSE) will be used for evaluating the bias, but other appropriate measures will also be considered.

The simulation modelling is expected to point the way to elucidating the most appropriate approach to tag modelling in IOTC stock assessments of tropical tuna species, based on the evaluation of the direction and magnitude of bias potentially induced by the non-random distribution of tag mixing, fishing effort, and/or the interaction of them.
Simulation results provided in 2019 will be preliminary and will indicate the potential for work to further develop the approach.

3 Results

Work on this project has only very recently started, and there are no results to report.

4 References

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