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SPATIOTEMPORAL TAGGING MODEL FOR SKIPJACK IN THE EPO

Tobias K. Mildenberger, Anders Nielsen, Mark Maunder

CONTENTS

1. SUMMARY

Historically, assessing skipjack tuna (SKJ, *Katsuwonus pelamis*) in Eastern Pacific Ocean (EPO) has been problematic due to the lack of a reliable index of relative abundance, the possibility of a dome-shape selectivity, and the lack of age-composition data, challenging its sustainable management. A spatiotemporal population model utilizing available tagging data might allow estimating the population size, distribution and sustainable harvest levels for SKJ in the EPO. As a first step, this model estimates the movement of SKJ as an advection-diffusion process. The advection process can be based on a spatiotemporal habitat preference function dependent on environmental layers, such as temperature or bathymetry maps, as described by Thorson *et al.* (2021). Instantaneous movement rates are transformed into movement and distribution probabilities by means of the matrix exponential. Preliminary results are promising and indicate that the mixed layer depth and temperature are likely to carry information about the habitat preference of SKJ in the EPO.

2. INTRODUCTION

Historically, assessing skipjack tuna (SKJ, *Katsuwonus pelamis*) in Eastern Pacific Ocean (EPO) has been problematic due to the lack of a reliable index of relative abundance, the possibility of a dome-shape selectivity, and the lack of age-composition data (Maunder, M.N. and Harley, S.J. 2005), challenging its sustainable management. On the other hand, available information from multiple tagging events might serve as the basis for a spatiotemporal population model that allows estimating the abundance and exploitation rates of SKJ (SAC-12-06). A core part of this model is the spatiotemporal tagging model that based on the recovered (and non-recovered) tags describes the most probable movement patterns of SKJ in the EPO. Here, we describe the approach used for the spatiotemporal tagging model that estimates the movement of SKJ in the EPO and present preliminary results.

3. DATA

The spatiotemporal tagging model requires information from recovered (and non-recovered) conventional tags as well environmental data.

3.1 Tagging data

Tagging data from four tagging events are available for SKJ in the EPO. So far, we utilized the conventional tags from the last two events that took place from 2000 to 2006 and the still ongoing event that started in 2019, but excluded the data from the other two tagging events that took place from 1955 to 1964 and from 1979 to 1981. While the six tuna tagging cruises in 2000 to 2006 targeted bigeye tuna, 3425 SKJ were tagged and released with plastic dart tags, of which 563 tags were recovered. By contrast, the IATTC multi-year Regional Tuna Tagging Program (RTTP-EPO 2019-2022, Project E.4.a) that was initiated in 2019 focused on SKJ. The RTTP included two tagging cruises in 2019 and 2020, with a third that was postponed and is currently ongoing (spring 2022). A total of 6259 SKJ were tagged with plastic dart tags during the first two cruises of which 1619 were recovered at the time of writing this report. The tuna tagged during these two events were released from 49 unique locations (yellow triangles in Figure 1).

After applying a speed filter and excluding unreliable tags, a total of 9625 tags remained, of which the 2007 recovered tags were used for the analysis presented here (black arrows in Figure 1). The spatial dimensions of the model region were defined to be within the Western management boundary at 150°W and the coastline of North and South America in the East as well as the 30°S and 35°N (blue area in Figure 1).

3.2 Environmental data

The SKJ tagging model requires environmental data to inform the habitat preference of SKJ. A range of potential environmental covariates could be relevant for informing the habitat preference and thus movement of SKJ in the EPO. So far, we explored sea surface temperature, the mixed layer depth, chlorophyll-a, as well as bathymetry data as potential covariates informing the habitat preference of SKJ. The environmental data is aggregated to correspond to the respective grid size (e.g. 5° or 2.5° grid cell sizes) and time step (e.g. quarterly or monthly).

4. MOVEMENT MODEL

The movement of SKJ in the EPO is described by an advection-diffusion process that utilizes a habitat preference function to define the advection (or taxis) process (Thorson *et al.* 2021). The movement is calculated by means of the matrix exponential of the instantaneous advection and diffusion rates. This allows the parameterization of the instantaneous movement rate among neighboring cells rather than among all cells (Thorson *et al.* 2017).

$$M(t) = e^{(A^{*}+D^{*})\Delta t}$$

where M(t) is the movement matrix per time step, and A^* and D^* are the instantaneous advection and diffusion rates, respectively. The instantaneous advection rate is defined by

$$A^*(g_2,g_1,t)=\begin{cases} h(g_2,t)-h(g_1,t) & if \quad g_1 \text{and} g_2 \text{are adjacent} \\ -\sum_{g'\neq g_1} A^*(g',g_1,t) & if \quad g_1=g_2 \\ 0 & if \quad otherwise, \end{cases}$$

where *g* and *t* correspond to the grid cell and time step, respectively, and $h(g,t)=\sum_{i=1}^{n} f_i(x_i(g,t),k_i)$ describes the habitat preference function as the sum of smooth functions f_i of the *i*th environmental layer $x_i(g,t)$ with knot vector k_i and corresponding parameter values α_i. Thus, the advection rate is defined by local differences in the habitat preference that is based on smoothed functions of any number of environmental layers. The instantaneous diffusion rate without environmental covariates is defined by

$$D^*(g_2,g_1,t)=\begin{cases} e^{2\beta} & if \quad g_1 \text{and} g_2 areadjacent \\ -\sum_{g'\neq g_1} D^*(g',g_1,t) & if \quad g_1=g_2 \\ 0 & if \quad otherwise, \end{cases}$$

where parameter β is the diffusion parameter.

As multiple recovered tags are linked to the same release locations (but various recovery times), the computations are optimized for computation speed and memory allocation by estimating the movement matrices dependent on the unique release locations. The spatiotemporal tagging model is implemented in the Template Model Builder (TMB; Kristensen *et al.* 2016) and parameter optimization is done in R 4.0.2 (R Core Team 2020).

5. PRELIMINARY RESULTS

Of various models tested so far, the spatiotemporal tagging model using the mixed layer depth and sea surface temperature as environmental layers was among the most robust models. Preliminary results of the model with 12 time steps per year indicate a high habitat preference around the equator with the highest values around 130° to 80° W (left plot in Figure 3). Two other regions with high habitat preference levels are around 20° N as well as in the lower left corner of the model region (around 30° S and 145° W). Thus, the estimated directed movement (here: advection) points towards these habitats with higher preference levels (right plot in Figure 3). In this model, the diffusion was estimated to be a constant rate independent of space and time.

Based on natural splines with three knots for each environmental layer, the model estimated that SKJ preferred a low mixed layer depth with continuously decreasing preference for increasing mixed layer depth and intermediate sea surface temperatures around 24°C (Figure 3). The scale of the habitat preference corresponding to the two environmental layers are in the same order of magnitude indicating a similar weighting of the two layers and thus contribution to the habitat preference of SKJ in the EPO (Figure 3).

Although these preliminary results were consistent for a model with a finer grid with 2.5° grid cells and 4 time steps per year, the relationships were dependent on the type and implementation of the splines, such as the number and position of knots or the number of bases for the B spline. Further, work will be allocated to compare different spline types and implementations and identify robust relationships between SKJ movement and relevant environmental layers.

6. DISCUSSION

These initial results are promising showing that movement rates can be estimate and suggest that the mixed layer depth and temperature are likely to carry information about the habitat preference of SKJ in the EPO. Preliminary analyses incorporating the effort data and non-recovered tags have been conducted and indicate that fishing and natural mortality rates may also be estimable. These quantities could be used to provide management advice directly or use to improve current management advice by integrating them into the interim stock assessment (SAC-13-07).

7. NEXT STEPS

Regarding the further development of the here outlined approach towards a population model that estimates the abundance and exploitation rate of SKJ in the EPO, the following short- and long-term steps will be considered.

Short-term steps:

- Utilizing archival tags to further inform the movement of SKJ
- Including non-recovered conventional tags
- Minimizing spatial and temporal resolution
- Exploring and comparing various environmental layers and spline types and implementations

Long-term steps:

- Utilizing spatiotemporal catch and effort data to estimate fishing and natural mortality rates
- Setting up a spatially-explicit abundance model informed by the estimated movement matrices
- Estimating reference levels for sustainable harvest
- Determining how the results can be integrated into the interim assessment (SAC-13-07).

7. ACKNOWLEDGMENTS

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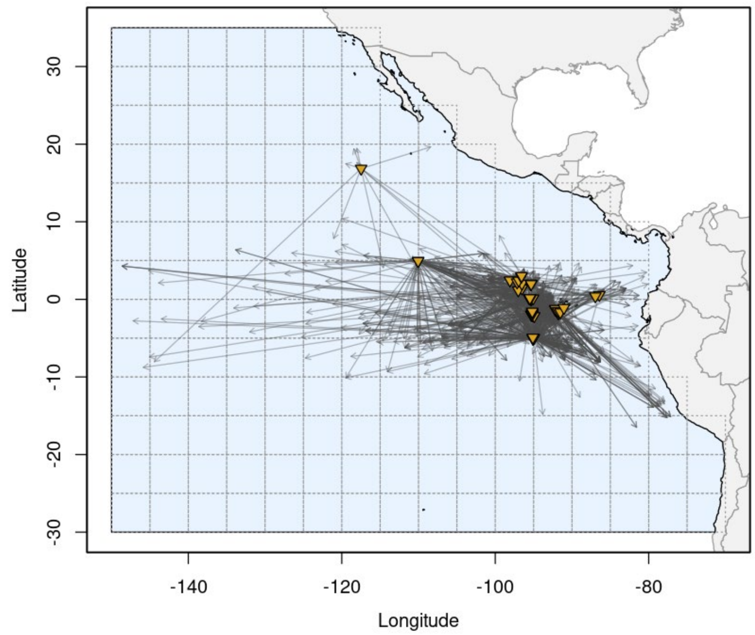

FIGURE 1. Spatial dimensions of the EPO model region arranged in two grids of 5° cell sizes. Black arrows connect the release and recapture location of SKJ with conventional tags from the two most recent tagging events. Yellow triangles indicate the 49 unique release locations.

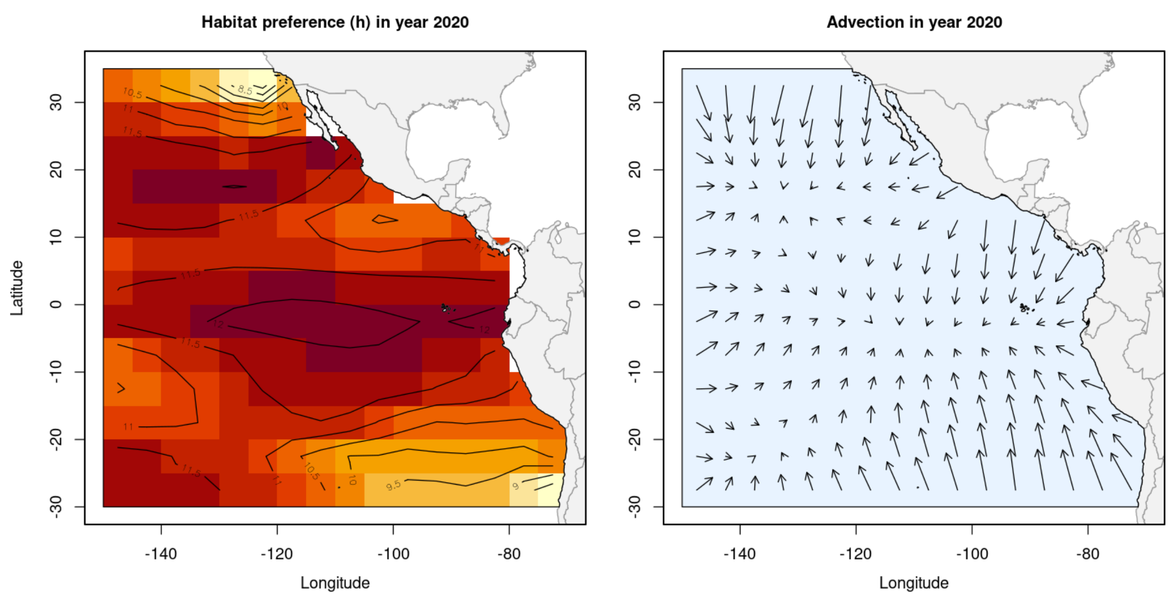

FIGURE 2. Estimated habitat preference and advection in 2020 based on a 5° grid, 12 time steps per year, and two environmental layers: mixed layer depth and sea surface temperature.

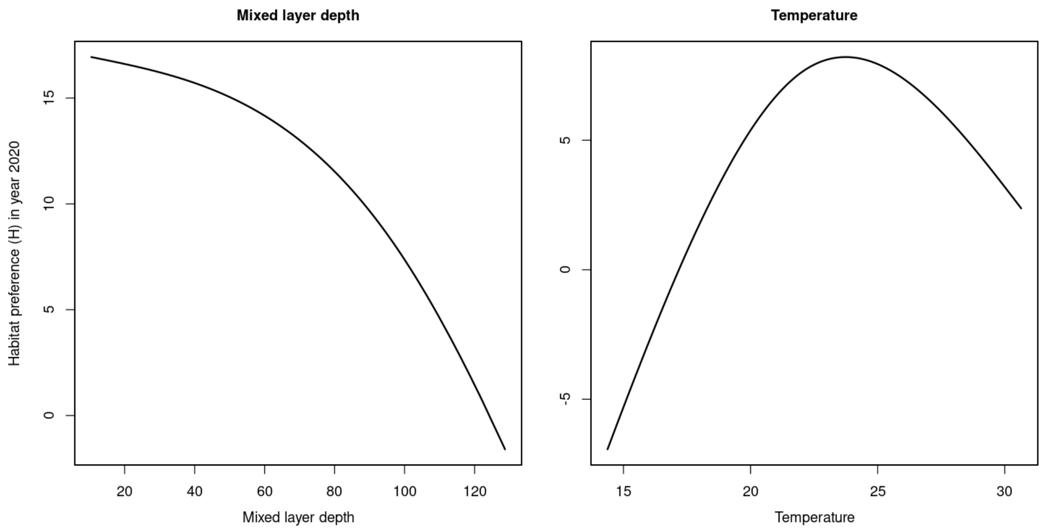

FIGURE 3. Relationship between habitat preference in 2020 and the two environmental layers estimated based on natural splines with three knots.