**Overview**

This paper seeks to evaluate the following objectives in a simulation framework:

1. How the nature of spatial fisheries dependent sampling patterns may bias estimated abundance indices
2. How temporal shifts in spatial sampling impact our ability to estimate temporal changes in catchability
3. How including an environmental covariate and/or a spatially varying coefficient in the formulation of the VAST model can affect the estimation of abundance indices given these shifts in spatial sampling.

These methods are then be applied to a real world application where spatial sampling has changed over time: the Japanese pole-and-line fishery for skipjack tuna in the western and central Pacific Ocean (WCPO).

**Methods**

The simulation uses as a base the SEAPODYM biomass field for adult skipjack tuna from 1979-2008 (1x1 degree spatial resolution & quarterly temporal resolution). The spatial frame of the simulation covers the spatial extent of the Western and Central Pacific Fisheries Commission (WCPFC) assessment boundaries from 102° E to 210° E longitude and from -20° S to 50° N latitude. The output from the SEAPODYM model is a smooth biomass field with positive non-zero abundance predicted for all 1x1 degree spatial cells (not including land). Fish distributions are known to be spatially patchy so areas of zero skipjack abundance were introduced. The abundance in each cell *x* and time *t* were randomly selected to be set to zero according to a single random draw from a multinomial distribution

Where was equal to 10% of the total number of cells () in the SEAPODYM output (rounded to the nearest integer) and where the probability of being selected as a zero cell was inversely proportional to the square root of the SEAPODYM abundance () at location *x* and time *t*.This had the effect that cells on the fringes of the spatiotemporal distribution of skipjack tuna were more likely to have zero abundance.

To address the first objective, was sampled under six different effort patterns (one fishery independent & five fishery dependent) with observation error.

Where is the observed or sampled abundance at each spatial cell *x* and time *t*. In the fishery independent pattern (hereafter referred to as the *random* sampling pattern) each spatial cell *x* had an equal probability of being selected, regardless of the underlying skipjack abundance. The five fisheries dependent effort patterns ([Figure 1](#Figure1)) were based on the principle that fishers are more likely to fish in areas of higher abundance. In contrast to the *random* sampling pattern, the *preferential* sampling pattern the probability of a spatial cell *x* being selected in any given year was proportional to . Spatial cells with higher levels of simulated abundance were more likely to sampled (or fished). was used, rather than , in order to allow for the sampling of cells with zero abundance.

It is well established that perceived underlying abundance does not solely drive the distribution of fishing effort in time and space, economic factors and regulatory restrictions can also dictate the distribution of fishing effort. Simplistically, spatial closures can exclude effort from areas that would otherwise be fished, and positive (negative) economic conditions can allow vessels to fish further away from (closer to) their home port. An additional four fisheries dependent sampling patterns were created, by modifying the base *preferential* sampling pattern, to explore how these external drivers impact the ability to estimate abundance. Two closure scenarios were created by applying temporally varying spatial closures to the *preferential* pattern. In the *fixed* closure scenario, fishing was prohibited south of 20° N during the 3rd quarter of the year. This is similar to the current FAD fishing closure imposed on purse seine vessels targeting tropical tunas in the WCPFC convention area. A second *rotating* closure scenario was created by closing each quadrant of the spatial sampling frame to fishing in successive quarters of the year. The quadrants were determined by bisecting the area along the 155° E longitudinal and 15° N latitudinal axes. Fishery *expansion* and *contraction* scenarios were created by applying a temporally varying maximum distance to the distribution of fishing effort on top of the *preferential* pattern. Japan was chosen as the “home base” for the hypothetical fishing fleet and the distance from Tokyo, Japan (139.692222° E ,35.689722° N) to every spatial cell *x* was calculated in kilometres using the *distHaversine* function from the *geosphere* package in R. In the *expansion* scenario, fishing effort was contained to a maximum distance of 1 000 km from Japan for the first 15 time-steps or quarters of the simulation (1/8th of the total simulation time of 30 years or 120 quarters). Over the next 90 time-steps the maximum distance was allowed to temporally vary according to a Brownian bridge which progressively relaxed the maximum distance to 10 000km by the 105th time-step in the simulation. All spatial cells *x* in the spatial sampling frame were able to be fished at this point, and this was maintained for the final 15 time-steps of the simulation. The effort *contraction* scenario, was created in the same way but with the pattern in time-varying maximum distance reversed.

A second set of simulations was developed to address the second objective. This second set of simulations was identical to the 6 effort sampling patterns described except that catchability effects ( for each vessel *v* and set *s* were added in addition to the observation error according to the following equations:

Where is the mean catchability for a vessel *v* and set *s,* is the unique vessel effect, is the vessel’s gear configuration effect, is the vessels class effect,

Each effort sampling pattern generated 60 000 total observations, and each time-step *t* had an equal probability of being sampled. Each combination of the six effort sampling patterns and two catchability patterns were simulated 100 times resulting in 1 200 total data sets used to estimate indices.

and two different types of observation error (lognormal & lognormal with catchability effects). VAST will be used to estimate indices under two sets of simulations, one with observation error only and a second with observation error and catchability effects. Each set of simulations will evaluate the following 4 model formulations: 1) VAST, 2) VAST + s(SST), 3) VAST + ENSO index, and 4) VAST + s(SST) + ENSO index.  Model performance will be evaluated relative to the “true” SEAPODYM index using as metrics bias, MAE, and coverage. Arnaud also suggested that we could evaluate the importance of SST and the ENSO index to explaining CPUE in the same way as your 2019 Limnology and Oceanography paper.

Anyways, let me know if you’re interested in contributing to this paper in some way, and feel free to come back to me with any questions you might have. I’m aiming to have the analysis completed and manuscript drafted by the end of your VAST workshop. I realize that’s a bit of a time crunch and also very short notice so no worries if you’re not comfortable with the idea.

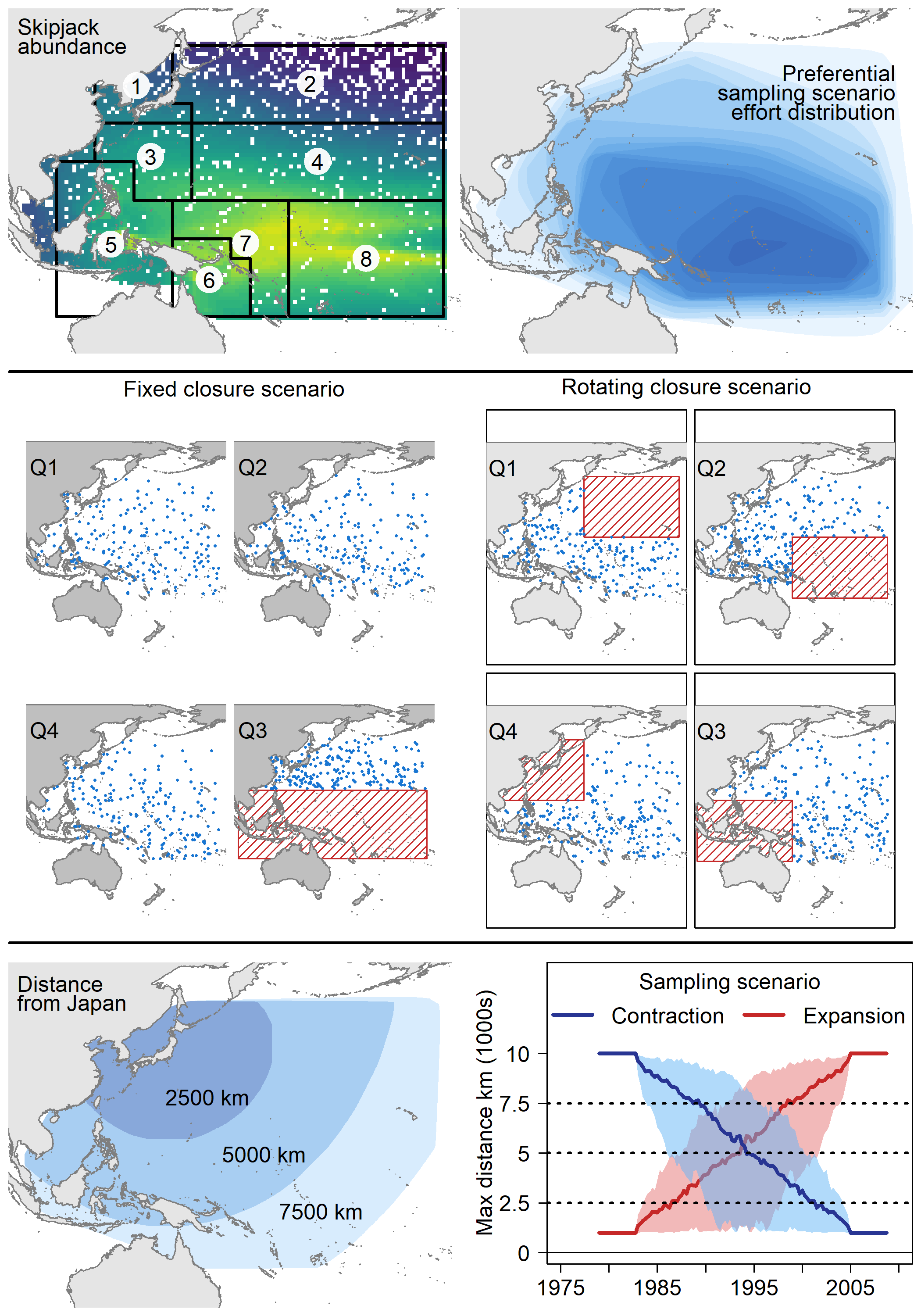


Figure Top left: Simulated spatial distribution of skipjack abundance in the first time period. Warmer colors indicate greater levels of abundance. The eight spatial regions of the 2019 WCPFC skipjack stock assessment are shown for reference. Top right: Simulated snapshot of the distribution of effort under the preferential effort pattern. Darker, more opaque blues indicate a greater density of effort. This corresponds to greater sampling in areas of higher skipjack abundance. Center left: The effort distribution under the fixed spatial closure scenario. In the 3rd quarter of the year no fishing takes place south of 20° N. Center right: The effort distribution under the rotating spatial closure scenario. In this scenario, quadrants of the spatial sampling frame are sequentially closed to fishing in each quarter of the year. Bottom left: Schematic indicating the approximate distances from Japan of locations within the spatial extent of the simulation. Bottom right: The maximum distance from Japan fished under the contraction (blue) and expansion (red) effort patterns in each time step of the simulation. The solid line indicates the median maximum distance for each effort pattern across all 100 replicates while the shaded region shows the 80th percentile across the replicates. The horizontal lines correspond to the distances depicted in the Bottom left panel.