Albacore tuna (*Thunnus alalunga*) habitat and variability in French Polynesia

M. Guinard[1], K. Maamaatuaiahutapu[2], H. Raapoto[3]

[1,2]University of French Polynesia, GEPASUD

[3]H. Raapoto, Direction des Resources Marine of French Polynesia

[*]Correspondence Author email: melina.guinard1@upf.pf

Abstract. Albacore tuna is important for the economy and food industry of French Polynesia. Nowadays, it represents 55% of the offshore fishery. With its lower resilience to climate change, relative to other tuna species, albacore requires focused study. This study investigates albacore's spatial distribution and relative abundance within the FP Exclusive Economic Zone (FP-EEZ) by analysing monthly fishery data from 2000 to 2022. Environmental parameters influencing Catch Per Unit Effort (CPUE) are assessed using a Generalized Additive Model (GAM) to define preferred habitat of albacore tuna. The parameters include sea surface temperature (SST), dissolved oxygen (DO) at 100m, chlorophyll concentration (Chl), sea surface salinity (SSS), and zonal and meridional currents. GAMs have the possibility to analyses past data in order to create a model that can predict on short and long-term time scale. Our results reveal a clear seasonal variability with a peak between May and December, and a pronounced interannual variation linked to El Niño Southern Oscillation. Our data show that part of the FP-EEZ is a spawning ground for albacore tuna, providing critical insights for sustainable fisheries management. GAM is a powerful tool to help making decisions as for a proper management of fishery resource in French Polynesia EEZ.

Keywords: Albacore tuna; Fisheries management; Generalized additive model; Spatial distribution; French Polynesia EEZ.

Presenter or Main Author Biography: M. Guinard is a PhD student at the University of French Polynesia, where she focuses on tuna stock modelling to support sustainable resource management in marine ecosystems.

1. INTRODUCTION

Seven million tons of tuna are landed annually, accounting for about 8% of total global marine capture fisheries (FAO, 2024a). The catch includes skipjack tuna (*Katsuwonus pelamis*, 57%), yellowfin (*Thunnus albacares*, 30%), bigeye (*Thunnus obesus*, 8%), and albacore tuna (*Thunnus alalunga*, 4%) (FAO, 2024b; ISSF, 2024).

The primary tuna fisheries are located in the South Pacific and are managed by two commissions: the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission-Conservation Area (IATTC-CA). The Western and Central Pacific Ocean (WCPO), under the jurisdiction of the WCPFC, contributes up to 51% of global tuna production (ISSF, 2024). In the southern WCPO, fishing activities are divided among distant-water longline fleets from Taiwan and China, and domestic longline fleets operated by Pacific Island Countries and Territories (PICTs), including French Polynesia (FP) (Chang *et al.*, 2021).

Located within the WCPO, French Polynesia is directly reliant on the WCPFC. In 2021, FP's tuna production represented only 0.3% of total fishing effort within the WCPFC, despite its large Exclusive Economic Zone (EEZ). Since 1990, FP has developed its own fleet of longliners which yield annually an average of 5,000 tons of pelagic fishes, reaching a peak of 7,528 tons in 2022. Tuna species account for 85% of this catch, with bigeye, yellowfin, and albacore tuna (Fig. 1). Tuna plays a central role in the local economy and represents a vital source of protein in the local food system

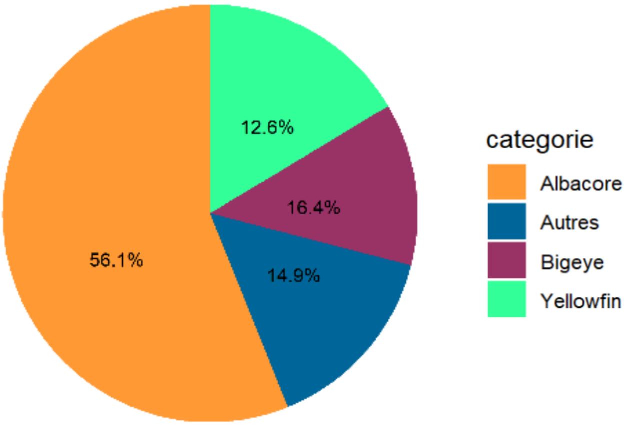

Fig. 1. Production Repartition of FP offshore fishery average from 2000 to 2022.

Offshore fishing in FP is particularly dependent on tuna, especially albacore, which constitutes over half of tuna landed. Although it benefits from consistent access to albacore stocks, the yield highly fluctuates on seasonal and interannual timescales. These fluctuations stem from the migratory behavior of albacore between spawning and feeding grounds.

To better understand and characterize the spatio-temporal variability of albacore tuna, we use a Generalized Additive Model (GAM) where part of the predictors are expressed as a sum of smooth functions (Hastie and Tibshirani, 1986). GAMs have been used to model albacore migration across different ocean basins with diverse spatial and temporal resolutions.

This study aims at improving our understanding of albacore habitat preferences by using a more complete and spatially detailed CPUE (Catch Per Unit Effort) dataset. We apply a GAM to link albacore abundance with environmental variables specific to FP waters.

2. MATERIAL AND METHOD

2.1 Fishery Data

The French Polynesian tuna fishery consists exclusively of longline fishing vessels. Established in 1988, the fishery has since expanded to include a fleet of approximately 80 longliners ranging from 13 to 24 meters in length. Only longline fishing is allowed in the FP EEZ and more than 70% of the hooks are deployed between depth of 50 and 250 m (Labelle, 2006).

Fishery data were provided by the Department of Marine Resources (DMR) of FP. Albacore tuna fishery data cover the period from 2000 to 2022 with a monthly resolution. The data were collected between 5°S and 30°S and between 160°W and 130°W (Fig. 2). The logbook includes data on number of individuals caught, number of hooks used and wet weight of fish for a given date and location. Averages have been carried out to form a 1° grid data set with a monthly resolution. Time series of albacore data are obtained at 391 locations (Fig. 2).

The index used to quantify the relative abundance of fish is the Catch Per Unit Effort (CPUE). CPUE is calculated using the following formula:

$$CPUE_{ymij} = \frac{Catch_{ymij}\ (Tons\ of\ albacore\ caught)}{Fishery\ Effort_{ymij}\ (No.of\ hooks\ used)}$$

where $CPUE_{ymij}$ represents the nominal CPUE within the 1° x 1° fishing grid for a given year y, month m, longitude i and latitude j.

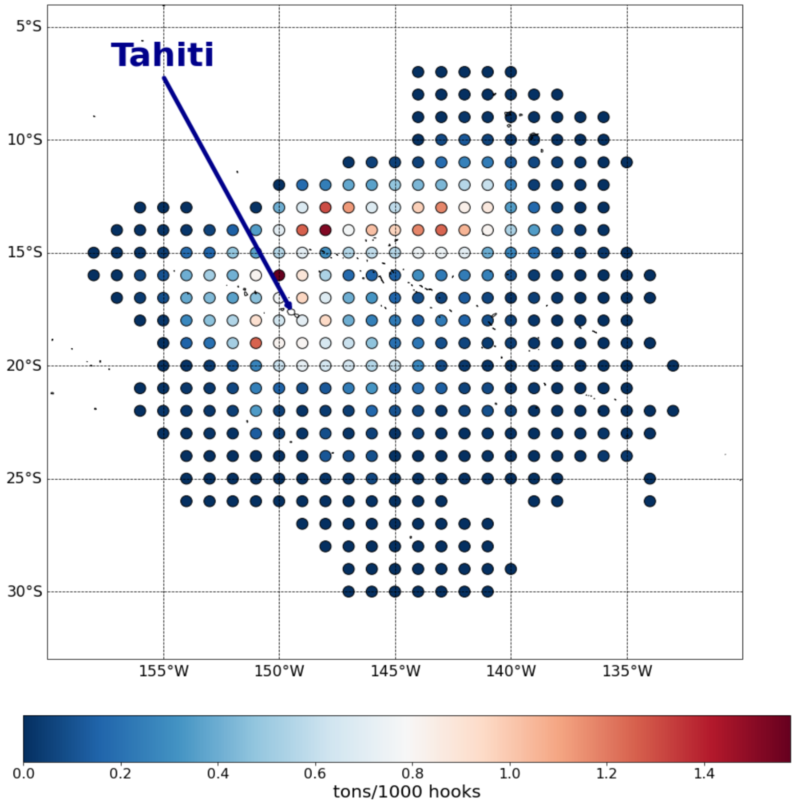

Fig. 2. Yield distribution across the Polynesian EEZ at 391 locations.

2.2 Environmental Data

The environmental parameters used in this study are obtained from the Global Ocean Biogeochemistry Hindcast model provided by the Copernicus Marine Service (https://data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_BGC_001_029/description).

The monthly data with a spatial resolution of 0.25° x 0.25° have been spatially averaged onto a 1° grid to match the CPUE data. The parameters chosen for our GAM are: seawater temperature, chlorophyll-a, salinity, dissolved oxygen at 100m, zonal and meridional currents. This choice is guided by what is commonly used in the literature to define the tuna habitats.

In order to study the effect of the El Niño Southern Oscillation (ENSO) on albacore distribution, the Multivariate ENSO Index (MEI) was used to identify 7-month periods within each year corresponding to strong El Niño, strong La Niña, and neutral phases. Based on this method, six La Niña events were selected: 2000, 2008, 2010, 2011, 2021, and 2022; two neutral phases: 2003 and 2004; and two El Niño events: 2015 and 2016. During these periods, the average albacore production was calculated using both observed and modelled catch per unit effort (CPUE), in order to assess the impact of ENSO events on albacore production within the FP-EEZ.

2.3 Generalized Additive Model

Environmental factors are known to significantly influence species distributions across ecosystems (Guisan and Zimmermann, 2000). The GAM is extensively used in fishery science. It allows to define the predictors as a sum of smooth functions of the explanatory variables (Hastie and Tibshirani, 1986), making it particularly well-suited for capturing complex and non-linear relationships between CPUE and environmental parameters (Mondal *et al.*, 2022).

In this study, albacore tuna CPUE is modelled as a function of 10 explanatory variables: latitude (lat), longitude (lon), chlorophyll-a concentration (Chl), surface sea salinity (SSS), surface sea temperature (SST), dissolved oxygen at 100 m depth (DO), zonal speed (u), meridional speed (v) and dates (month and year). The mathematical formulation of between CPUE and environmental parameters is as follow:

$$log(CPUE + h) \sim \beta + s_1(lat) + s_2(lon) + s_3(Chl) + s_4(SSS) + s_5(SST) + s_6(DO) + s_7(u) + s_8(v) + te(month, year) + \mathcal{E}$$

Where h is a small constant, set at 10% of the total CPUE average, added to address issues related to log transformation (Chang *et al.*, 2021), s_i are the spleen smooth functions, te is the tensor smooth function, β is the intercept term and $\mathcal{E}$ is the residual term. The model is based on statistics and we assume that the response variable follows a Gaussian distribution.

After several runs, the best model is selected based on statistical criterion: lowest Akaike Information Criterion (AIC) and highest adjusted correlation (R^2). In our case, the best GAM gives an AIC of 71,000 and a R^2 of 0.16.

3. RESULTS AND DISCUSSION

3.1 Temporal variation

The time variability is analysed through climate indicators like the annual variability (season), the interannual variability associated to ENSO, and the decadal variability like the Interdecadal Pacific Oscillation.

Fig.3 shows the time series of the spatially averages of albacore CPUE and the predicted CPUE by the GAM. As expected, the predicted CPUE are underestimated but its time variability is similar to the observed CPUE. The time series shows that there is a seasonal signal, an interannual signal and also a decadal oscillation even though the time series is short. Indeed, a climatological monthly analysis confirm the seasonal signal with low CPUE values from January to April and high CPUE values from May to December. The interannual signal, with periods between 2 and 8 years, is also clear on Fig. 3. As an example, the difference between the 130 tons in 2016 and the 90 tons in 2017 is due to ENSO.

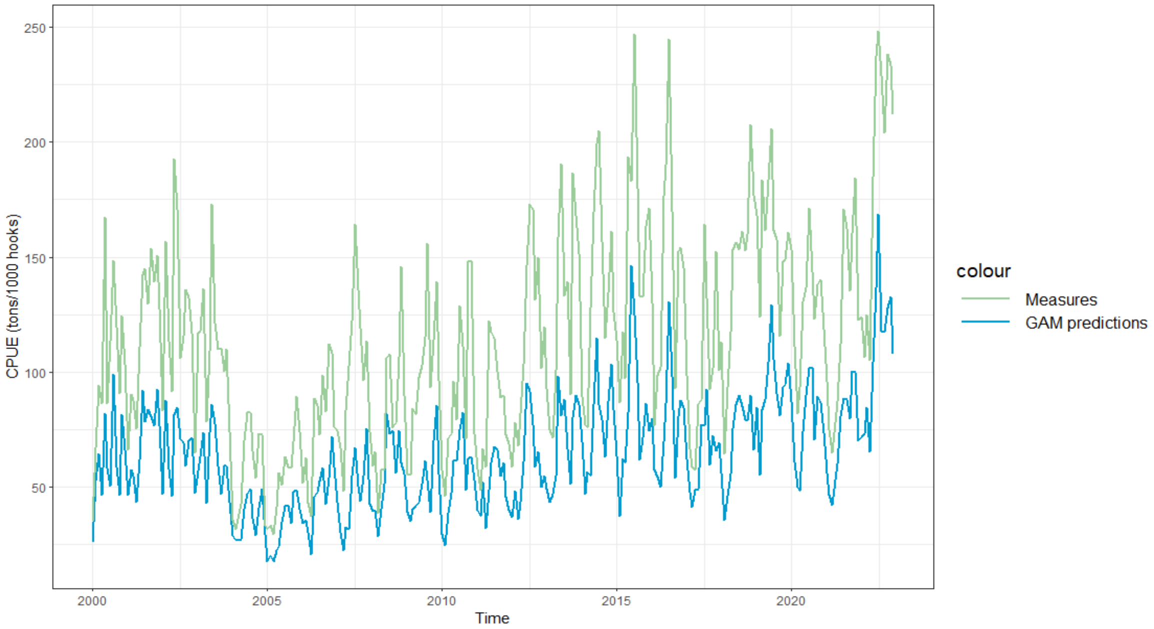

Fig. 3. Spatially averages of Albacore CPUE (in green) and GAM predicted CPUE (in blue) from 2000 to 2022.

3.2 Seasonal Spatio-temporal Distribution

Fig. 4 shows the spatial and temporal distribution of monthly CPUE (both observed and predicted values). For readability reason, only February (low production month) and November (high production month) are selected to illustrate the spatial distribution of albacore tuna. Fig. 4 shows that our model determine fairly well the locations where the catches are low or high. As previously reported, from January to April, CPUE remains low and start to rise around May, particularly between 10° and 23°S and 155° to 137°W. June and July mark the peak abundance, as indicated by the dominance of red patches. Tuna is mainly located in the same region as in May; however, in June, a particularly high abundance (>1 ton/1000 hooks) is observed between 9–16°S and 141–151°W. By July, this high-density zone expands with an additional hotspot emerging between 17–22°S, may be ling to a tuna migration. In August, abundance declines but remains concentrated around 9–16°S and 141–151°W, as seen in June and July. The decline continues into September, followed by a secondary peak in November, before decreasing again in December.

Albacore tuna is known to spawn in equatorial waters, between 10 and 25°S, where temperatures exceed 24°C during the austral summer, between September and January (Ramon and Bailey, 1996; Senina *et al.*, 2020; Williams *et al.*, 2012). In addition, albacore tuna is mature and only reproduce if they exceed 14 kg weight (Farley *et al.*, 2012, 2013). Our data show that the albacore tuna caught between 10 and 25°S weight more than 14kg. Mature albacore tuna is found in the FP-EEZ around November when optimal conditions are met.

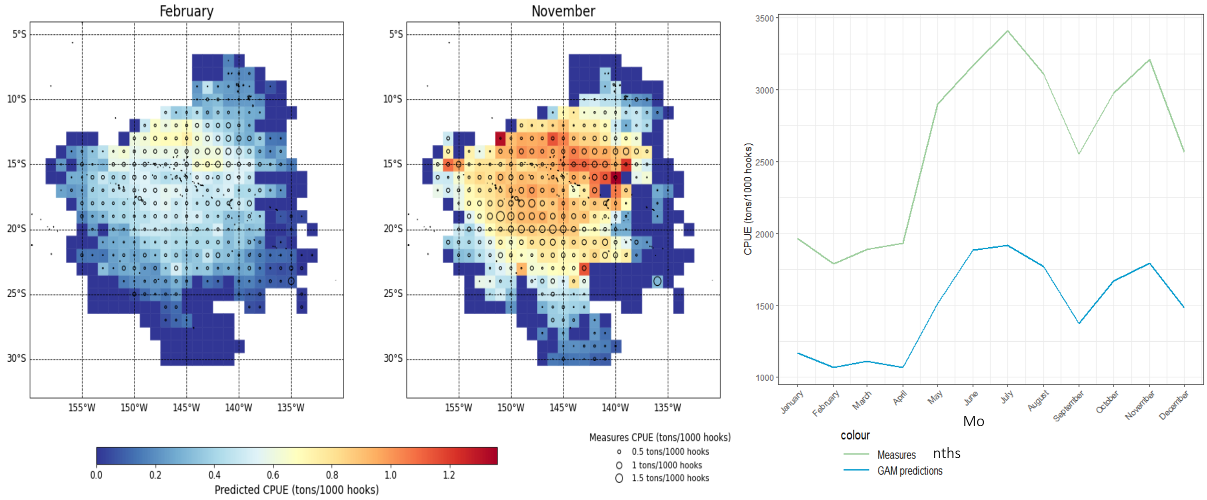

Fig. 4. (Left and Middle) Monthly spatial distribution of true CPUE (circles) and predicted CPUE (color gradient). (Right) Spatially averages of Albacore CPUE (in green) and GAM predicted CPUE (in blue) from January to December.

3.3 Interannual Spatio-temporal Distribution

The South Pacific Ocean conditions changes with ENSO which includes a warm phase (El Niño), a cold phase (La Niña), and a neutral phase. The change of oceanographic conditions would affect the spatial distribution of albacore tuna (Fig. 5).

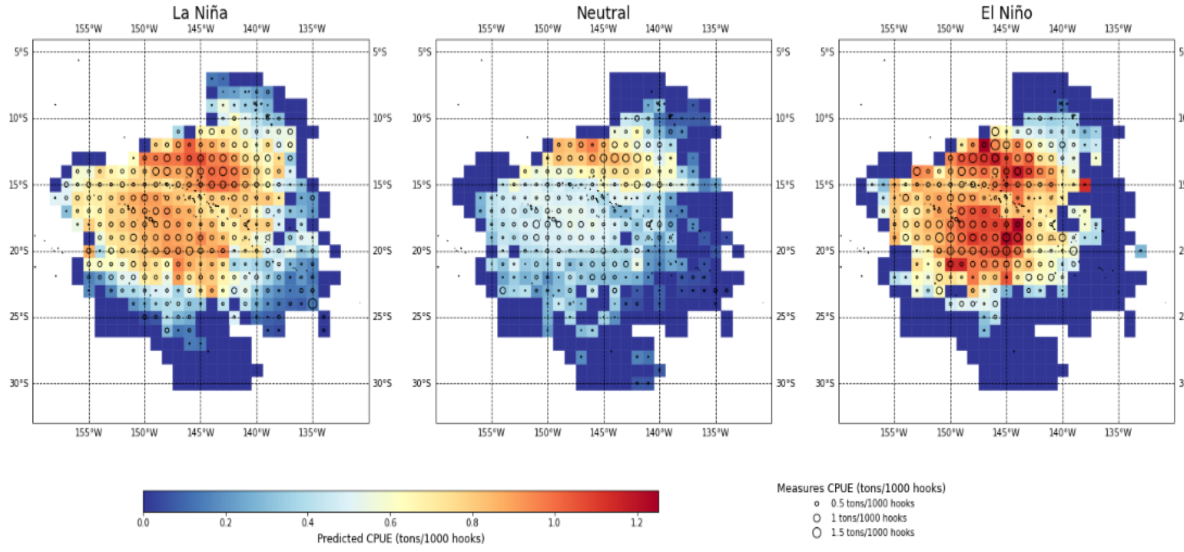

Fig. 5. True CPUE (circle) and predicted CPUE (color gradient) for La Niña (left), for neutral phase (center), and for El Niño (right).

The highest CPUE values are observed during El Niño years, with values exceeding 0.8 tons/1000 hooks between 11–24°S and 154–141°W. Two high CPUE zones (>1 ton/1000 hooks) are noticeable: one between 11–14°S and 155–141°W, and another between 17–22°S and 151–144°W. During La Niña, high CPUE values are found in similar areas as for El Niño but with lower values. During a neutral phase, CPUE values are the lowest.

4. CONCLUSION

This study, based on GAM, is the first done in the FP-EEZ in order to investigate the spatial and temporal variabilities of albacore tuna distribution within the French Polynesia EEZ. Our analysis shows a high-productivity period between May and December, and that during El Niño there is an increase in albacore tuna catch. We also show that the conditions are met to consider the FP-EEZ as a major spawning ground for albacore tuna. In a future work, the GAM will be used to predict albacore tuna abundance under several climate change scenarios.

ACKNOWLEDGEMENTS

We would like to thank the *Délégation à la Recherche* of the French Polynesian Government for funding this project and for awarding M Guinard receive a grant . We thank the *Direction des Ressources Marines* of French Polynesia for providing us with the pelagic fish data.

REFERENCES

Chang, Y.-J., Hsu, J., Lai, P.-K., Lan, K.-W. and Tsai, W.-P.: Evaluation of the Impacts of Climate Change on Albacore Distribution in the South Pacific Ocean by Using Ensemble Forecast. Frontiers in Marine Science 8, 731950, (2021).

Farley, J.H., Williams, A.J., Davies, C.R., Clear, N.P., Eveson, P., Hoyle, S.D. and Nicol, S.J.: Population Biology of Albacore Tuna in the Australian Region. CSIRO Oceans and Atmospheric Research, p. 124 (2012).

Farley, J.H., Williams, A.J., Hoyle, S.D., Davies, C.R. and Nicol, S.J.: Reproductive Dynamics and Potential Annual Fecundity of South Pacific Albacore Tuna (Thunnus alalunga). PLoS ONE 8(4), e60577 (2013).

FAO (Food and Agriculture Organization of the United Nations), World Global Tuna Fisheries. FIRMS - Fishery Fact Sheet, https://firms.fao.org/firms/fishery/459/, last accessed 2024/11/08.

FAO (Food and Agriculture Organization of the United Nations), Tuna & Biodiversity. Common Oceans ABNJ Tuna Project, https://www.fao.org/in-action/commonoceans/projects/tuna-biodiversity/en/, last accessed 2024/11/07.

Hastie, T. and Tibshirani, R., Generalized Additive Model. Statistical Science 1(3), 297–318 (1986).

ISSF (International Seafood Sustainability Foundation), ISSF 2024-02: Status of the World Fisheries for Tuna, https://www.iss-foundation.org/about-issf/what-we-publish/issf-documents/issf-2024-02-status-of-the-world-fisheries-for-tuna-march-2024/, last accessed 2024/04/18.

Mondal, S., Wang, Y.-C., Lee, M.-A., Weng, J.-S. and Mondal, B.K.: Ensemble Three-Dimensional Habitat Modeling of Indian Ocean Immature Albacore Tuna (*Thunnus alalunga*) Using Remote Sensing Data. Remote Sensing 14(20), 5278 (2022).

Ramon, D. and Bailey, K.: Spawning seasonality of albacore, Thunnus alalunga, in the South Pacific Ocean. Fishery Bulletin 94, 735–733 (1996).

Senina, I.N., Lehodey, P., Hampton, J. and Sibert, J.: Quantitative modelling of the spatial dynamics of South Pacific and Atlantic albacore tuna populations. Deep Sea Research Part II: Topical Studies in Oceanography 175, 104667 (2020).

Williams, A.J., Farley, J.H., Hoyle, S.D., Davies, C.R. and Nicol, S.J.: Spatial and Sex-Specific Variation in Growth of Albacore Tuna (*Thunnus alalunga*) across the South Pacific Ocean. PLoS ONE 7(6), e39318 (2012).