Effect of inter-FAD distances on the movements of tuna in an array of FADs: an empirical modeling approach

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Summary

Understanding the effects of increasing FAD densities on the movements and ecology of tropical tuna is key to provide science-based advices on the limits in the total number of FADs. Previous electronic tagging studies conducted on different arrays of FADs allowed characterizing the time spent by tuna associated with FADs and out of them. In this paper, we combined these data with a model of tuna motion in an array of FADs. Tuna motion was simulated through a correlated random-walk model, that mimics a random-search behaviour of tuna in the FAD array. The parameters that set the tuna motion, namely the sinuosity of the trajectory and the orientation radius (i.e. the distance at which tuna can detect the FADs) were calibrated using the field data collected on three different arrays of anchored FADs (Hawaii and Mauritius) characterized by distinct FAD densities. Our results show that the model can best fits the field data for an orientation distance of 5-7 km and a low sinuosity of the correlated random-walk motion (c=0.8-0.94). The model was then run on different FAD-array densities and the relation between the inter-FAD distances, the connectivity of the FAD array and the time spent by tuna out of the FADs were derived.

Introduction

Fishermen and scientists have been observing the associative behaviour of tuna to floating objects for decades and even centuries (Dempster & Taquet, 2004), but the reasons and mechanisms behind such behavior are still unkown (Dagorn *et al.* 2013). However, the number of man-made floating objects (FADs) has sharply increased these last two decades with their rise in tuna purse seine fishing (Dagorn *et al.* 2013 and Miyake *et al.* 2010). In order to give science-based advices on the management of the number of FADs, it is essential to better understand these tuna-FAD interactions. Previous studies, using acoustic tagging data on anchored FAD (AFADs) arrays around islands, have characterized the time that tuna spent associated at one FAD (Continuous Residence Time - CRT) and spent out of FADs (Continuous Absent Time – CAT) (Rodriguez et *al.* 2017, Govinden et *al.* 2013, Robert et *al.* 2013 and Dagorn et *al.* 2007). These studies highlighted the variability of these variables according to the species and the environment, even at the scale of individuals (Robert et *al.* 2013). While coded acoustic tagging data are appropriate to measure the time variables of the associative behavior, they do not provide details on the movements of individuals (e.g. paths). Using active tracking data of 14 yellowfin tuna tracked in AFAD arrays, Girard et *al.* (2004) found that tuna adopt a random search behaviour in the ocean until they detect a FAD, then orient towards it and stay at the FAD or leave it. The authors defined a range of detection distance between 9 and 11 km (totally extended from 4 to 17 km). Our study combines these data with a model of tuna movement in different FAD arrays, to the purpose of understanding the effects of changing FAD densities on tuna movements. The parameters defined to characterize tuna movement (TABLE 1 – parameters 1 and 2) were calibrated using the acoustic tagging data. Then, once the model was fitted with the calibrated parameters, the effects of changing FAD densities on tuna movements were tested.

Material and Methods

To model tuna movements in an array of FADs, we considered a correlated random-walk model, i.e., a random walk taking into account the tendency of the animal to go straigtforward with a bilateral symmetry. The model contained two main parameters: (1) the sinuosity of the tuna path and (2) the FAD orientation radius, namely the distance from which individuals are able to detect a FAD (TABLE 1 – parameter 1 and 2). The sinuosity parameter *c* was related to the turning angle as follows:

$$c = \exp(\frac{-\sigma}{2})$$

Where sigma is the standard deviation of the distribution of turning angles, that follows a normal distribution N(0,σ) (knowing that this turning angle correspond to the change of direction of tuna for each step of the simulation*).*

Every time a tuna individual crosses the orientation radius of a FAD, it goes straight to the FAD whatever the time of the day (called "persistent model" below), or this directional movement depends on the time of the day (called "diel model" below).

TABLE 1: Model parameters names and values tested. In bold the parameters chosen as model best fit.

	Parameter	**Values**
1	Sinuosity (c)	0.4, 0.6, **0.8, 0.94** and 0.98
2	Orientation radius (D_{zo}) (km)	2, **5, 7** and 10
3	Distance between FAD (km)	15, 20, 30, 40, 50, 60, 70, 80, 90, 100

In order to find the best model that could describe tuna motion in an array of FADs, we fitted the model to field data considering two different acoustic tagging datasets collected within two arrays of anchored FADs, offshore Mauritius (Rodriguez et *al.* 2017) and Oahu (Hawaii) (Robert et *al.* 2013) islands. The artificial environment of the model reproduced the actual numbers and positions of the FADs, as well as the shoreline contours of each island. The comparison between the field data and the model outpust were done considering the distribution of Continuous Absent Time (CAT), namely the time between two subsequent FAD associations (Capello et *al*. 2015), considering only the movements between different FADs. We calculated the sum of square residuals (SSR) between the modeled and observed CAT distributions, considering different values of sinuosity (from a very sinuous path to a straight motion) and different FAD orientation radius, both for the "persistent" and "diel" model. The best model fits were selected considering the range of parameters with the minimum SSR and the best q-q plots.

Finally, considering the model parameters that best fitted the field data, we considered an environment with a regular FAD grid (with FADs showing a constant distance between each other, see TABLE 1 – parameter 3) and we calculated how the time between two FAD associations depends on the inter-FAD distance.

Results and Discussion

The diel model provided the best fit of the field data, for both islands, for a sinuosity ranging between 0.8 and 0.94 and an orientation radius between 5 and 7 km (TABLE 1 – parameter 1 et 2 in bold). The results of the best fitted model for the theoretical environments are presented in Fig. 1. For the first time, the model allows to predict the effects of increasing FAD densities on the time that tuna spend unassociated.

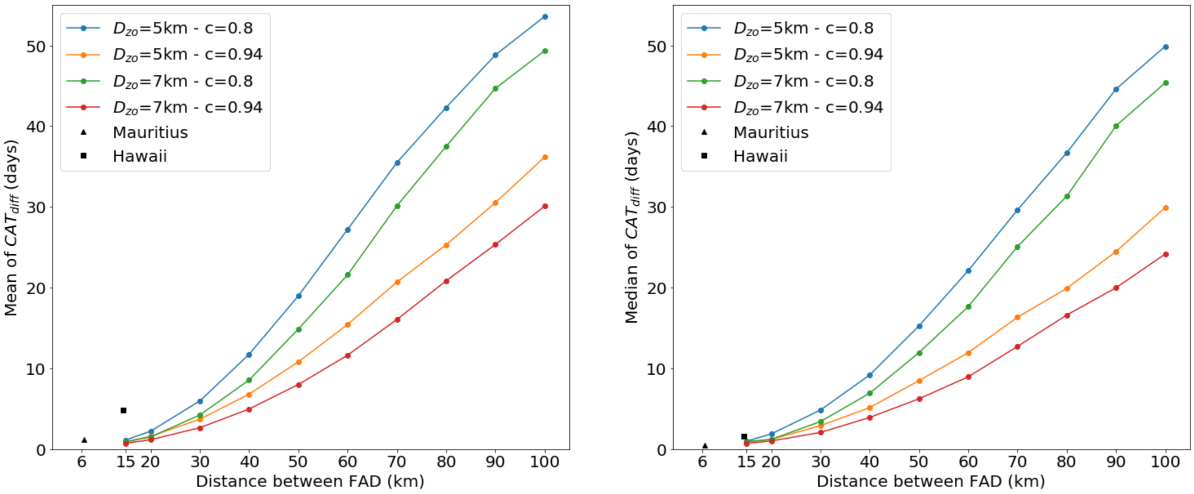

FIGURE 1: Mean (left) and median (right) of the time spent between two different FADs according the distance between FAD and for the best models describing the tuna motion in an array of FADs.

References

Bovet P. and Benhamou S. 1988. Spatial analysis of animals' movement using a correlated random walk model. Journal of Theoretical Biology, 131: 419-433.

Capello M., Robert M., Soria M., Potin G., Itano D., Holland K., Deneubourg J-L. And Dagorn L. 2015. A Methodological Framework to Estimate the Site Fidelity of Tagged Animals Using Passive Acoustic Telemetry. PLoS ONE. 10.8: 1-19.

Dagorn L., Holland K. N. and Itano D. G. 2007. Behavior of yellowfin (Thunnus albacores) and bigeye (T. obesus) tuna in a network of fish aggregating devices (FADs). Marine Biology, 151: 595-606.

Dagorn L., Holland K. N., Restrepo V. and Moreno G. 2013. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? Fish and Fisheries, 14: 391–415.

Dempster T. and Taquet M. 2004. Fish aggregation device (FAD) research : gaps in current knowledge and future directions for ecological studies. Fish Biology and Fisheries, 14: 21-42.

Girard C., Benhamou S. and Dagorn L. 2004. FAD: Fish Aggregating Device or Fish Attracting Device? A new analysis of yellowfin tuna movements around floating objects. Animal Behaviour, 67.2: 319-326.

Govinden R., Jauhary R., Filmalter J., Forget F., Soaria M., Adam S. and Dagorn L. 2013. Movement behaviour of skipjack (Katsuwonus pelamis) and yellowfin (Thunnus albacares) tuna at anchored fish aggregating devices (FADs) in the Maldives, investigated by acoustic telemetry. Aquatic Living Resources, 26: 69-77.

Miyake M. P., Guillotreau P., Sun, C-H. And Ishimura G. 2010. Recent developments in the tuna industry: Stocks, fisheries, management, processing, trade and markets. FAO: Fisheries and Aquaculture technical paper. 125 pp.

Robert M., Dagorn L., Filmalter J.D., Deneubourg J-L., Itano D. and Holland K. 2013. Intra-individual behaviour variability displayed by tuna at fish agregating devices (FADs). Mar Ecol Prog Ser, 484: 239-247.

Rodriguez-Tress P., Capello M., Forget F., Soria M., Beeharry S. P., Dussooa N. and Dagorn L. 2017. Associative behavior of yellowfin Thunnus albacares, skipjack Katsuwonus pelamis, and bigeye tuna T. obesus at anchored fish aggregateing devices (FADs) off the coast of Mauritius. Mar Ecol Prog Ser, 570: 213–222.