Vertical migrations of Bigeye tuna: A time series analysis based on dynamic optimal foraging

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Abstract: Bigeye tuna is known for remarkable vertical migrations between deep layers, where food is abundant but the water is too cold to maintain high swimming speeds, and the surface, where water is warm but food is scarce. In a modeling study, we have investigated if these dive patterns can be explained by dynamic optimal foraging theory, where the individual tuna aims to maximize its average energy gain rate. Using a state-space approach, where the tuna is characterized by its mean body temperature and its vertical position, we solve this dynamic optimization problem numerically using dynamic programming. Unknown parameters are estimated statistically based on time series of depth, ambient water temperature, and body temperature, measured at the individual. The time series analysis follows the gray box paradigm and employs a predictive filter based on stochastic differential equations to evaluate the likelihood function. The study reveals lack of robustness of the maximum likelihood estimator, which can be attributed to fast sampling in combination with unmodeled fast dynamics, and which can be remedied by extending the prediction horizon of the filter, thus departing from the maximum likelihood framework. The final model, being conceptually simple while technically sophisticated, is able to explain the main patterns in the data, although not all features, which we discuss. We find that the optimal strategies bifurcate from constant-depth strategies to vertical migrations, when the tuna is sufficiently large or the food is at sufficiently cold water layers. The study demonstrates the feasibility of combining dynamic optimization models with time series analysis, all in a consistent state-space framework. The analysis supports the hypothesis that the tuna behaves such as to maximize its net energy gains, and allows to predict foraging behavior in unobserved environments, for example in future scenarios.