Performance evaluation of shallow versus normal depth FADs in the eastern equatorial Pacific tuna purse-seine fishery

A collaborative effort by IATTC, ISSF, and NIRSA

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Introduction

- Bigeye tuna (BET) stock(s) in the Pacific Ocean exploited by purse-seine (PS) fisheries targeting tuna aggregations associated with drifting fish-aggregating devices (FADs), are probably overfished and overfishing taking place.
- Conservation management measures adopted by IATTC to reduce fishing mortality on BET are inadequate, as purse seine fishing effort (number of sets on FADs) has significantly increased in recent years.
- Recent studies have been conducted to evaluate factors contributing to catches of BET by PS vessels in the Pacific, including investigations of spatio-temporal distribution of catch and effort (Sibert et al., 2012, 2015; Harley, 2015; Schaefer, 2015), fishing gear configurations (PS net and FAD depths) (Lennert-Cody et al. 2007; Satoh et al., 2008; Delgado et al., 2010), as well as fine-scale behavior of BET relative to skipjack (SKJ) and yellowfin (YFT) tunas around FADs (Schaefer and Fuller, 2005; 2013; Matsumoto et al., 2006); each attempting to reveal practical solutions for reducing BET fishing mortality.
- Although large dynamic time-area closures in the Pacific may be effective at reducing BET fishing mortality, such measures would significantly reduce SKJ catch due to overlapping high catch areas. Also, it does not appear that reducing PS net depth is a viable solution because of the required minimum PS net depth to catch SKJ and the small differences in depth between SKJ and BET when associated with FADs. The study by Satoh et al. (2008) reported that FAD depth in the WCPO was not a significant factor in their general linear models as to BET catch, but area/time was significant. However, Lennert-Cody et al (2007) reported that FAD depth in the EPO was a significant factor in their random forest model as to BET catch, as were area/time effects.
- The objective of this field experiment is to evaluate the performance of shallow versus normal depth FADs in the EPO PS fishery, with an emphasis on the tuna species catch composition; seeking a practical solution to reduce purse-seine fishing mortality on BET

Materials and Methods

- ISSF made arrangements for the field experiment to be undertaken in collaboration with Negocios Industriales Real S.A. (NIRSA), a vertically integrated large diverse seafood company located in Posorja, Ecuador, with a fleet of 11 PS tuna vessels and a large tuna cannery.

- Two experiments were conducted, the first from June 2015 through October 2016, and the second from March 2017 through December 2017.

- Prior to departure of the fishing trip for experiment 1, during which the 100 experimental FADs were to be deployed, Kurt Schaefer spent time at the NIRSA facility to examine and confirm the construction specifications of the FADs and discuss the experimental design with the fleet manager, the Captain of the FV Milena A, and the IATTC scientific observer assigned to that trip.

- Prior to departure of the fishing trip for experiment 2, during which the 200 experimental FADs were to be deployed, Kurt Schaefer spent time at the NIRSA facility to confirm the configuration of the FADs to be deployed and discuss logistics and deployment strategies of the FV Via Simoun.

Materials and Methods – FAD Design

- For both experiments the rafts for the shallow and normal depth FADs were similar dimensions (approximately: 1.2-1.5 m x 2.0-2.3 m) and construction materials. The appendages hung beneath the normal depth FADs were approximately 37-46 m, and consisted of 1 or 2 coils of twisted and tied scrap tuna or sardine netting weighted with chain. The appendages hung beneath the shallow FADs were approximately 5 m, and consisted of 4 ropes (1-2” dia) with coconut palm fronds tightly laced, attached to a split bamboo frame weighted with chain.

- Marine Instruments (MI) M3i echo-sounder buoys (50 kHz, 50 depth intervals 3m/ea, 5 min sampling frequency) were attached to each of the 300 FADs. Arrangements were made to receive the M3i buoy data for every FAD in real time, utilizing the MI software.

Materials and Methods– FAD Design

Marine Instruments M3i Buoy

Raft construction

Materials and Methods – FAD Design

Normal Depth FAD

Shallow Depth FAD

Materials and Methods – FAD Deployment

- The normal and shallow depth FADs for experiment 1 were deployed from the NIRSA FV Milena A (62m length, 900 t capacity) simultaneously in pairs along 7 transects between 3°S -1°N and 89°-107°W during 25 June through 20 July, 2015. Each deployment was recorded by the navigator on a data form created specifically for this project which included data fields for FAD type, deployment position and date, M3i buoy number and the NIRSA ID numbers assigned and painted on each buoy. In addition, the IATTC observer monitored and recorded each of the deployments so as to independently verify the FAD types with the buoy ID numbers.

- The normal and shallow depth FADs for experiment 2 were deployed from the NIRSA FV Via Simoun (69m length, 975 t capacity) simultaneously in pairs along 2 transects between 2°S -2°N and 100°-116°W during 9 March through 13 March, 2017. Deployment metrics were recorded similarly to those in experiment 1.

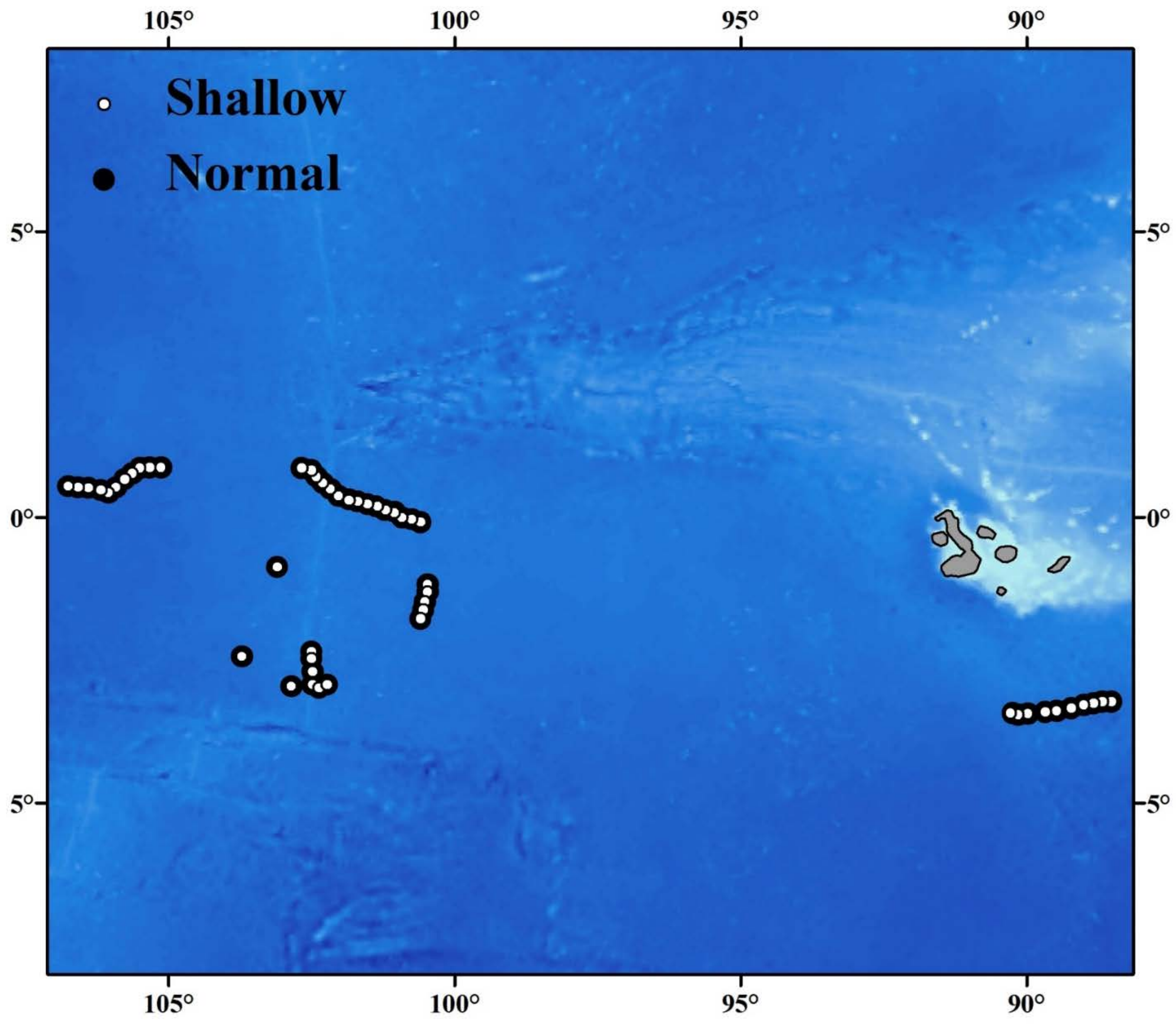
Materials and Methods – Deployment Vessels

Experiment 1, FV Milena A

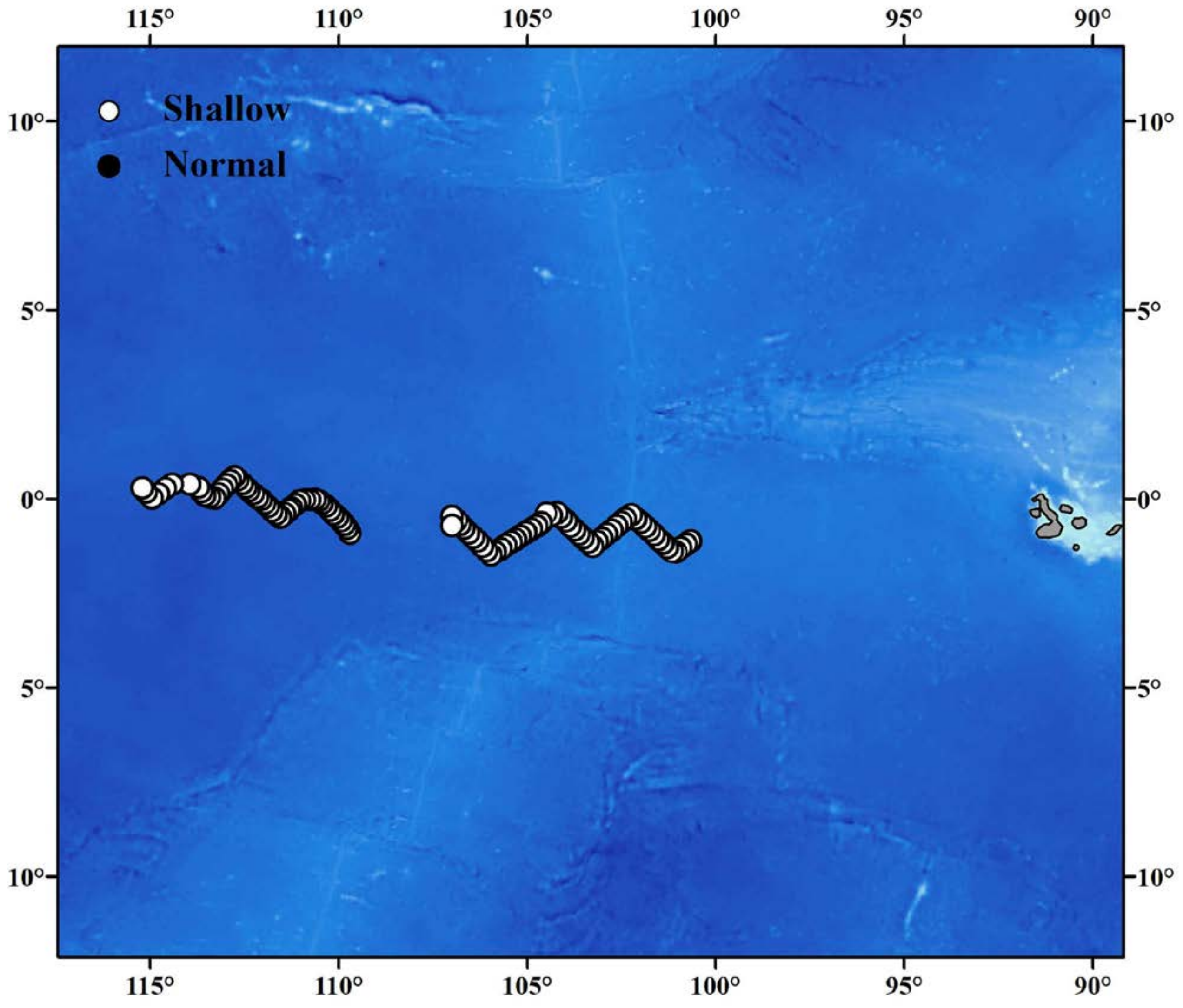
Experiment 2, FV Via Simoun

Materials and Methods – FAD Deployment Locations

Experiment 1



Experiment 2



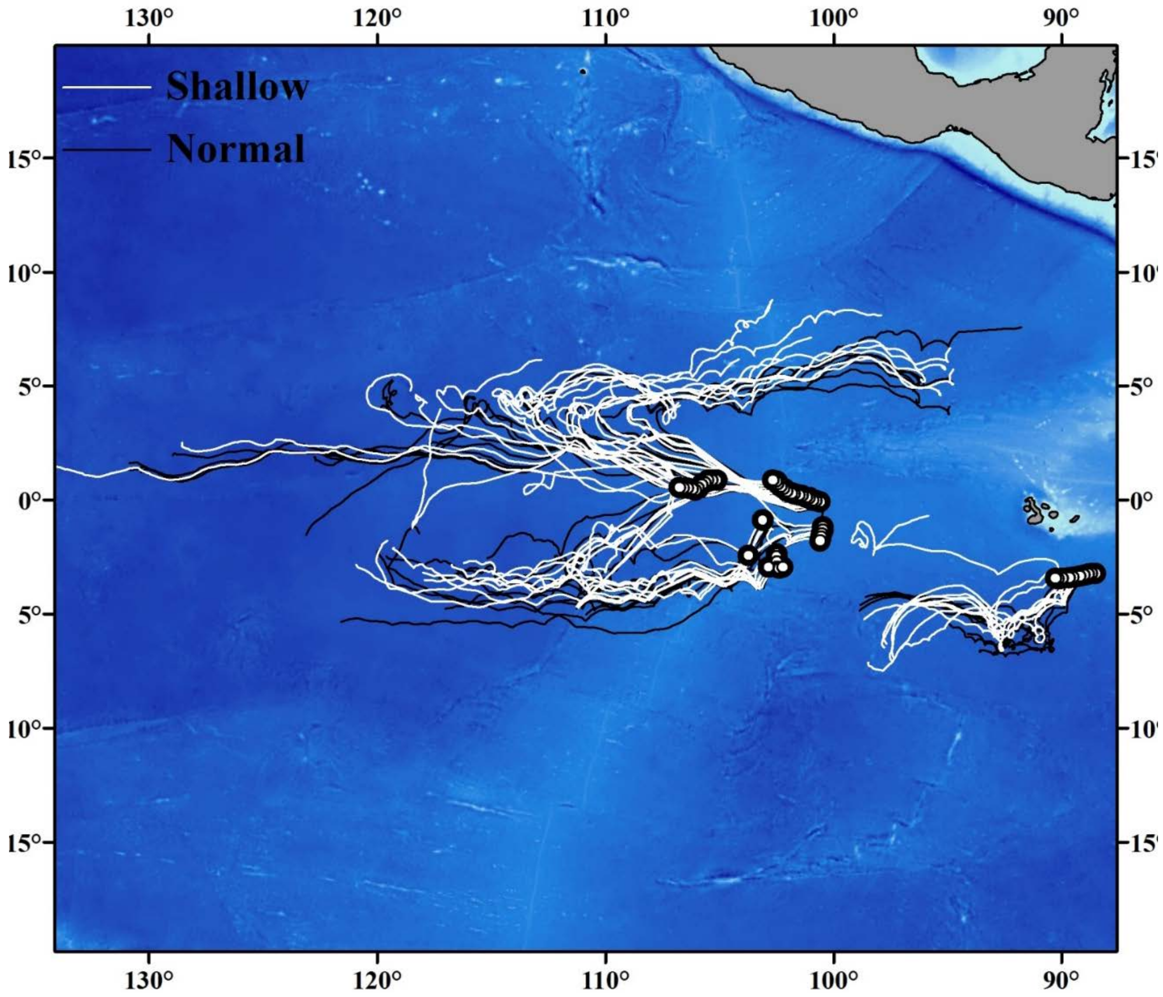
Materials and Methods– Data Analyses

- A Bayesian statistical approach was chosen over frequentist statistics because it is fundamentally sound, very flexible, produces clear and direct inferences, and makes use of all available information (O'Hagan and Forster, 2004).
- A Bayesian inferential procedure was used to fit a range of different geo-additive generalized additive mixed regression models (GAMMs) to the set-specific tuna catch (tons/set) by species and for combined species
- The response variable was catch (t) per set given 5 predictors: FAD type, species, month, set hour, and set location
- A spatial effect was included as the catch came from throughout a large area of the equatorial EPO
- 1 random effect was included (Set) to account for how the data was sampled
- An explicit interaction term between species and FAD type was included for catch by species
- An explicit interaction term between proportion of bigeye captured and FAD type was included for total catch
- Models were fit using the Stan computation engine with NUTS sampling via the brms package for R
- Models were implemented using weakly informative regularizing priors with posterior samples sourced from four chains and 12 k iterations after a warm up of 2000 iterations
- The best fit models were determined using leave-one-out information criteria (LOOIC)
- 3 posterior probability predictive check tests (density overlay, maximum prediction, and two summary statistics (mean, standard deviation) were used to confirm adequate model fits

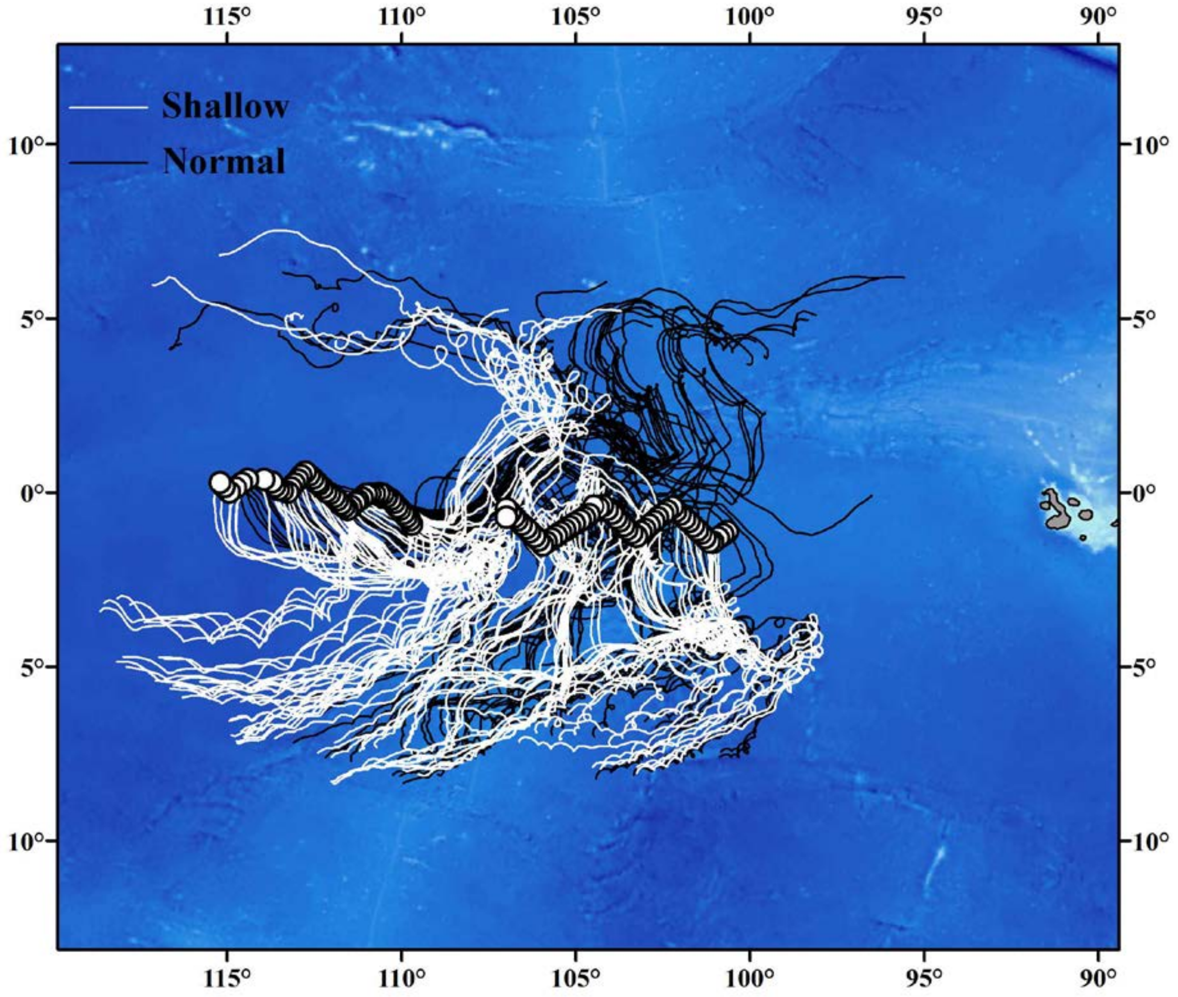
Results – FAD Trajectories up to 60d and Drift Speeds

Average drift speeds for both experiments combined were 0.73 and 0.72 knots for normal and shallow depth FADs respectively. ANOVA indicates there was no significant difference in the mean daily drift speeds between normal and shallow FADs ($F = 2.583$, $P = 0.11$)

Experiment 1

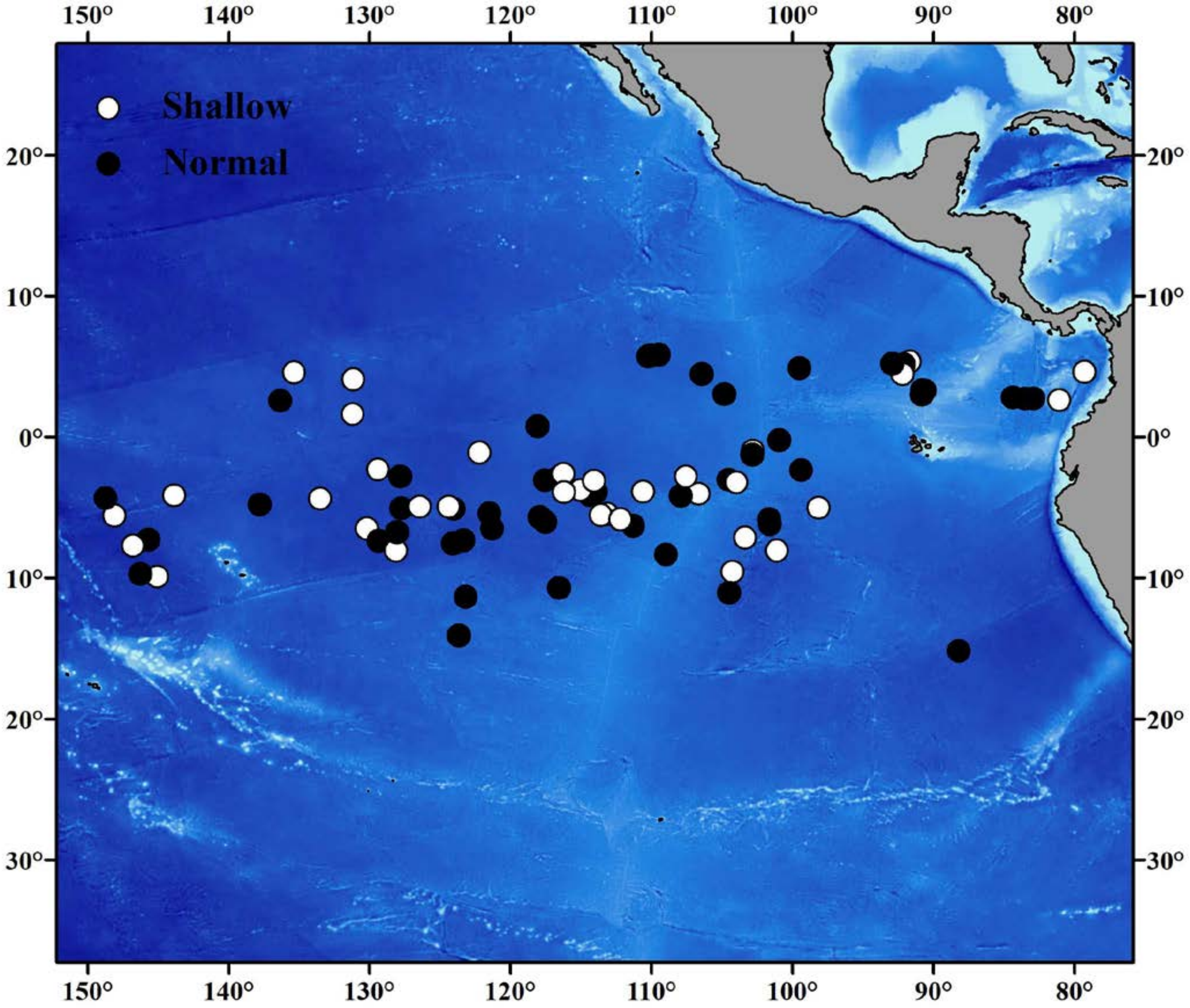


Experiment 2



Results – Set Locations

Locations of 84 sets on normal and shallow depth FADs



Results – Set and Catch Metrics

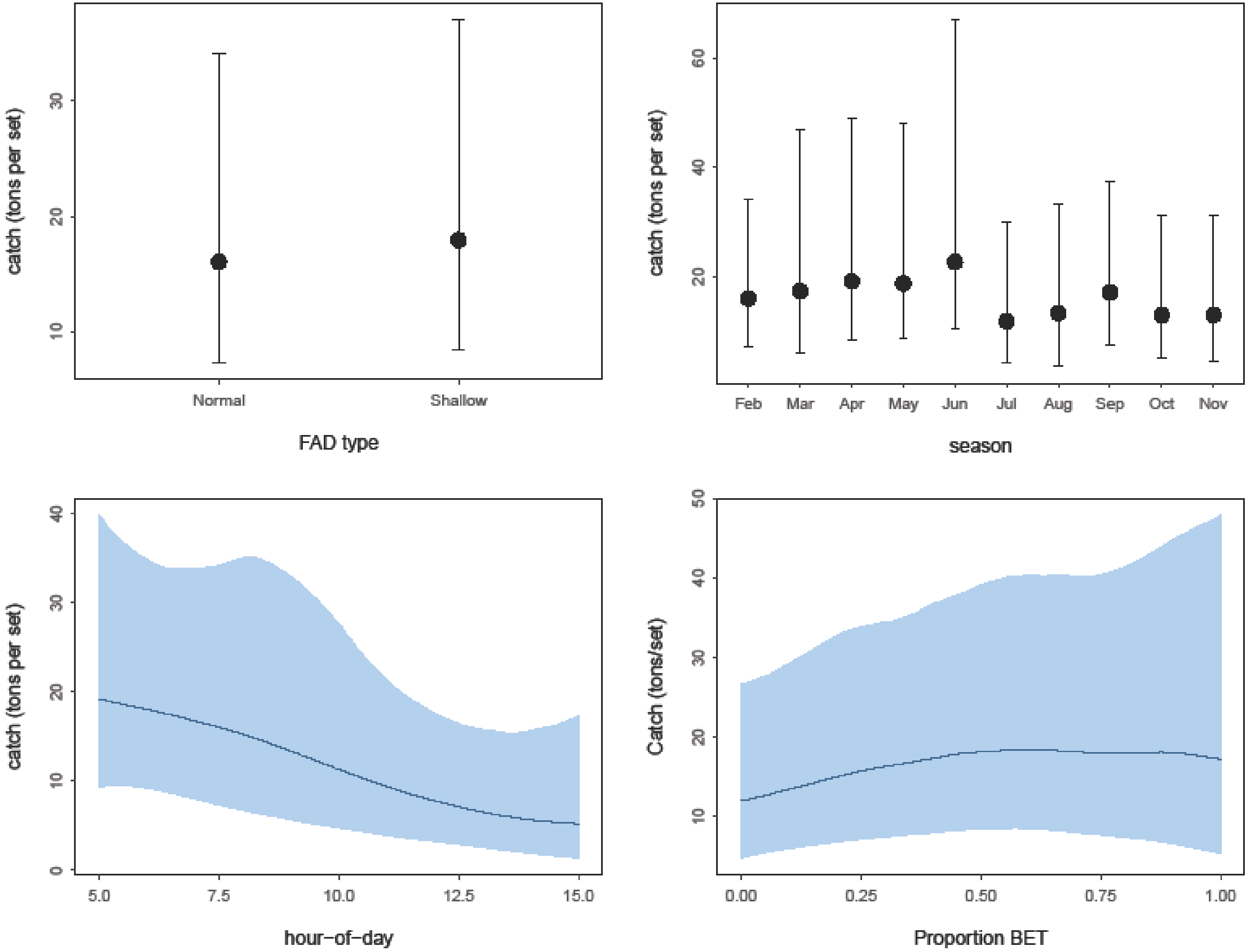
Summary of 84 sets by 11 NIRSA vessels on normal and shallow depth FADs

	Normal	Shallow
Number of sets (% FADs)	49 (33 %)	35 (23 %)
Range in set dates	7/16/2015 – 11/06/2017	7/19/2015 - 10/13/2017
Range in set locations	15 S - 6 N, 91 W - 148 W	10 S - 5 N, 81 W - 149 W
Average (range) SKJ catch (t)	9.8 (1 - 117)	13.0 (0 - 144)
Average (range) BET catch (t)	6.6 (0 - 134)	6.7 (0 - 35)
Average (range) YFT catch (t)	1.2 (0 - 20)	2.9 (0 - 13)
Average (range) total tuna catch (t)	17.6 (0 - 140)	22.6 (0 - 153)
Average (range) proportion of BET	0.28 (0 - 0.96)	0.26 (0 - 0.83)

Results– Total Tuna Catch Rates

- The best fit model for total tuna catch rate is a Bayesian geo-additive GAMM with Poisson likelihood
- The response variable is total tuna catch rate given 5 predictors with Set included as a random effect:
  - **CatchT ~ FAD + s(prop.bet) + Month + s(time) + t2(lon, lat) + (1 | SET)**
  - Only Set was significant in predicting total tuna catch rate
  - Proportion BET nor any of the other covariates, including FAD type, were significant predictors of set specific total tuna catch rates
  - There was no significant interaction between FAD type and proportion of BET captured.

Results– Total Tuna Catch Rates



Results – Tuna Species Catch Rates

- The best fit model for tuna species catch rates using LOO cross validation is a Bayesian geo-additive GAMM with negative binomial likelihood

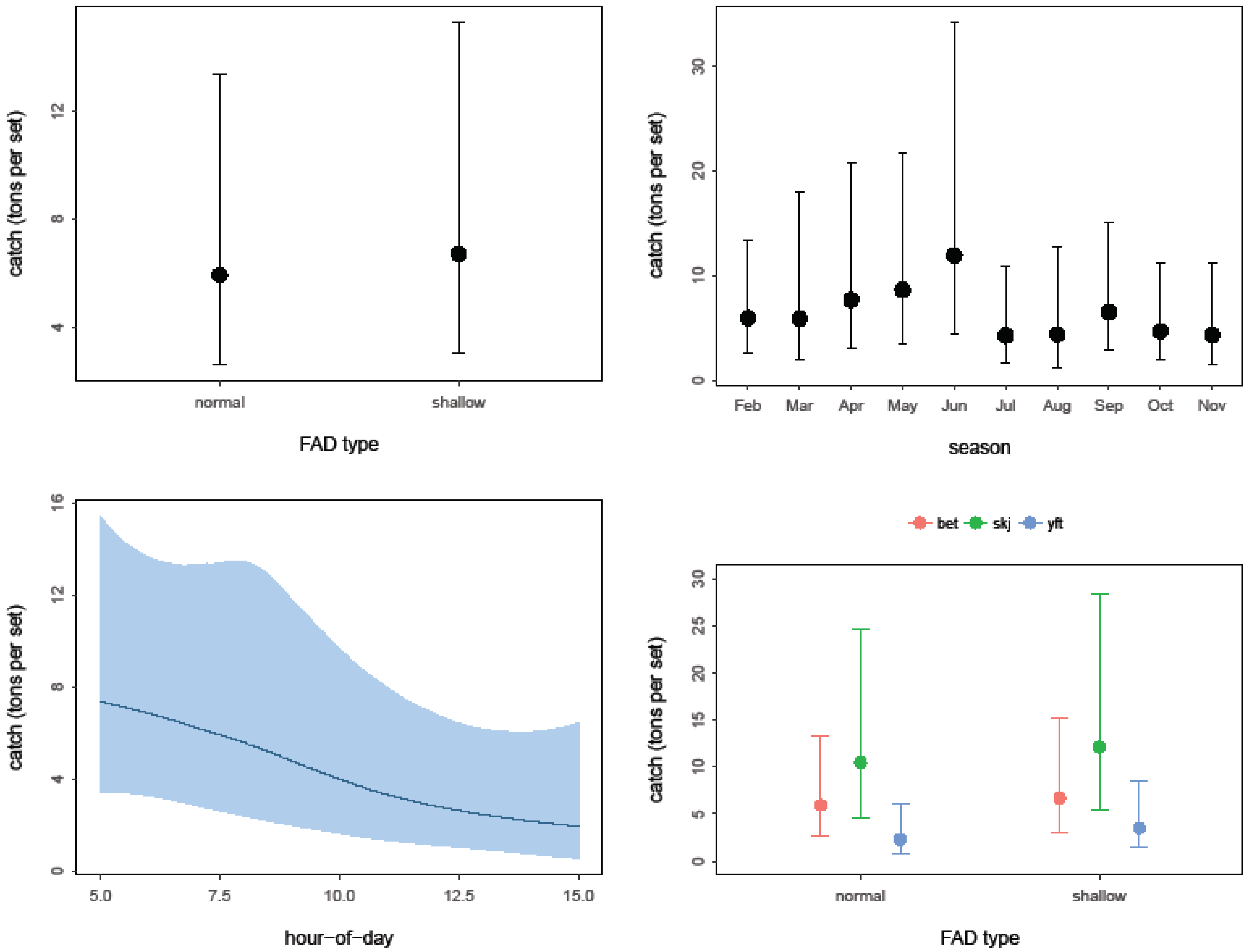
- The response variable is tuna species catch rates given 5 predictors with Set included as a random effect:

  - **Catch ~ FAD * species + Month + s(time) + t2(lon, lat) + (1 | SET)**

  - Only Set was significant in predicting tuna species catch rates

  - There is an interaction between FAD type and tuna species catch rate. However, as indicated by a higher standard error, the interaction between FAD type and species is both marginal and uncertain.

Results – Tuna Species Catch Rates



Conclusions

- There was no significant difference in drift speeds between normal and shallow depth FADs
- Total tuna catch rates and tuna species catch rates were not significantly different by FAD type

Forthcoming Analyses

- Additional Bayesian GAMMs will be run and evaluated with some measures of effort (net depth, and time of set to rings up) and some environmental variables (SST, CHL, and Frontal Strength)

- Include Catch rates of non-tuna species, retained and discarded, by Set in GAMMs

- Evaluate the total tuna and non-tuna catch by set with the M3i echo-sounder buoy data preceding sets

- Estimate time until colonization by tuna aggregations for all FAD deployments, using the M3i echo-sounder buoy data

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Questions