

OBSERVED HOOK DEPTH AND CATCH DISTRIBUTION IN THE SRI LANKAN TUNA LONGLINE FISHERY

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Purpose

The purpose of the paper is to inform WPM of study on observed hook depth and catch distribution in the Sri Lankan tuna longline fishery.

Abstract

Hook depth determines the depth range fished by a tuna longline and may influence species composition and catch rates, yet it is usually inferred from gear geometry rather than measured. This study compared catenary-derived hook depths with direct observations from Star-Oddi DST centi-TD temperature-depth recorders (TDRs) on a Sri Lankan tuna longline on a single vessel which gear was typical of about half of 27 surveyed vessels. It also examined how the catch of yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), sailfish (*Istiophorus platypterus*) and other fish species varied with hook depth and hook position. Theoretical depths were calculated with a catenary curve using a sag ratio of 0.85. Across 100 hook-level TDR records from 22 sampling dates and five sensors, mean observed depth was 71.0 m, compared with a mean theoretical depth of 87.1 m. The raw mean difference was -16.1 m, equivalent to 18.5% of the mean theoretical depth. A mixed model estimated a mean bias of -16.7 m (95% CI: -23.2 to -10.2 m), with observed depths shallower than theoretical estimates in 82% of records. Bias did not differ detectably among four hook-position groups ($p = 0.125$), but variation among dates was large (SD 12.2 m). Catch records matched to TDR depths (71 records, 62 with catch, 195 fish) were analysed as species shares among fish caught, using binomial mixed models. Observed depth in meters was not significantly associated with the share of any species after correction for multiple testing. In exploratory analyses, species shares varied along the line: modelled swordfish share rose from 18% at the end hooks to 47% at the central hooks, whereas sailfish share fell from 27% to 4%, and yellowfin share did not differ detectably (22–31%). These hook-position differences were not significant after Holm correction (adjusted $p \geq 0.064$) and should be treated as hypotheses. The catenary calculation overestimated the depth fished by about 17 m on average, so hook depth should be measured rather than assumed when describing fishing effort, catchability and CPUE in tuna longline fisheries.

Keywords: hook depth, tuna longline fishery, temperature-depth recorder, catenary, species composition, fishing effort

1. Introduction

Pelagic longlines are passive fishing gear target tuna and billfish by suspending baited hooks at different depths below the surface (K. Bigelow et al., 2006). The depth of a hook determines the temperature, light and oxygen conditions it fishes in and the species that encounter it, so it is a central variable in understanding catchability and in standardising catch per unit effort (CPUE) (Bigelow & Maunder, 2007; Stoner, 2004). Many pelagic species have characteristic vertical habitats, and catch composition is known to change with the depth range fished by the gear (Bigelow & Maunder, 2007; Ward & Myers, 2005).

In most longline fisheries, hook depth is not measured. It is calculated from gear geometry (the length of the mainline between floats, the lengths of buoy lines and branch lines, and the number of hooks between floats) using a catenary curve and an assumed sag ratio (K. Bigelow et al., 2006). These calculations assume a stationary line shaped only by its own weight and buoyancy. At sea, current shear, vessel speed during setting, the shortening of the line and the behaviour of hooked fish can all move the line away from that shape, and studies using depth recorders have reported that observed hook depths often differ from theoretical depths (Campbell & Young, 2012; Ward & Myers, 2005). For estimation of the depths fished by a longline, the number of hooks between floats is used as a proxy but has limitations (Bach et al., 2008). The maximum hook depth at the deepest hook can be calculated using catenary geometry and validate it with temperature-depth recorders (TDRs). Setting depth is managed by altering the number of hooks between floats and the shortening rate (the ratio of vessel speed to line setting speed). However, environmental factors such as strong currents can drag the gear up, reducing actual hook depth relative to theoretical catenary predictions (K. Bigelow et al., 2006).

Thetuna longline fishery of Sri Lanka targets yellowfin tuna (*Thunnus albacares*) and also catches bigeye tuna (*T. obesus*), swordfish (*Xiphias gladius*), striped marlin (*Kajikia audax*), blue marlin (*Makaira nigricans*), black marlin (*Istiompax indica*), Indo-Pacific sailfish (*Istiophorus platypterus*) and other species. The fleet targets both EEZ and high-seas waters using a wide variety of gear configurations (Hewapathirana & Gunawardane, 2016). Most vessels (~94%) are under 15 m long (Hewapathirana et al. 2025), where limited deck space and manual handling of gear limits the number of hooks and length of trips. Large offshore vessels with mechanized haulers regularly set 1,000–2,500 hooks per set (Hewapathirana et al., 2025). Fishing effort in this fishery is usually described by the number of hooks, without depth information. If theoretical depths are biased, or if species vary systematically with hook position, then effort and CPUE based on hook counts alone may not describe what the gear actually fished.

This study uses TDRs attached to branch lines on a Sri Lankan tuna longline to compare observed hook depths with catenary-derived depths and test whether the difference varies with position along the basket, and examine how the share of yellowfin tuna, swordfish, sailfish and other species in the catch varies with observed hook depth and with hook position.

2. Materials and Methods

To place the experimental gear in context, gear configurations were collected from a survey of 27 vessels at representing tuna longline harbors (Negombo, Dikowita, Beruwala, Dondra, Kottegoda and Nilwala) by interviewing skippers. Dimensions were recorded in fathoms and converted to meters (1 fathom = 1.8288 m).

The longline gear used for the TDR observations had 1,500 hooks, with eight hooks between adjacent buoy lines. The branch-line length was 42.98 m, the distance from the buoy line to the first branch line was 23.77 m, the buoy-line length was 25.60 m, and the distance between successive branch lines was 47.55 m. All observations were made on a single vessel of length 12.1 m and operate within EEZ of Sri Lanka between 23.12.2023 and 17.05.2024. Hooks within each basket were numbered 1 to 8 from one buoy line to the next. Hooks were paired by symmetrical position about the centre of the basket into four hook-position groups: 1 and 8 (adjacent to the buoy lines), 2 and 7, 3 and 6, and 4 and 5 (central).

Depth was recorded with Star-Oddi DST centi-TD temperature-depth recorders attached to hooks at a sampling interval of 2 minutes. For each deployment the mean corrected depth was used as the observed depth of that hook for the full soak period. The dataset contained 100 hook-level records from 22 sampling dates and five sensors.

Theoretical hook depths were calculated for each hook position with a the catenary equation of Yoshihara (1951), as presented by Bigelow et al. (2006) and a sag ratio of 0.85, using the gear dimensions given above. Bias was defined as observed minus theoretical depth, so negative values mean the hook was shallower than calculated.

Catch was recorded by hook (branch-line position) for the monitored sections: the number of yellowfin tuna (YFT), swordfish (SWRD), sailfish (SAIL) and OTHR includes bigeye tuna, marlins and all other species. Catch records were matched to TDR depth records by date, sensor and branch-line position. Of 100 catch records, 71 matched a TDR record. Species counts summed to the recorded total for every matched record. Records with no catch (9 of 71) carry no information on composition and were excluded from the composition analyses, leaving 62 records from 19 dates and four sensors.

All analyses were done in R version 4.4.3 (R Core Team, 2025) using *lme4*, *lmerTest*, *glmmTMB*, *DHARMA* and *emmeans* packages.

Depth bias (observed minus theoretical depth) was estimated with a linear mixed model with random intercepts for date and sensor (REML, Satterthwaite degrees of freedom). Differences among hook-position groups were tested by likelihood-ratio test with a date-only random intercept, because the sensor variance was singular in the group models. Pairwise contrasts used Tukey adjustment.

For the catch composition the counts of each species and of all other fish in each record were modelled with a binomial GLMM (logit link, random intercept for date). Observed depth was centred and scaled per Depth bias. 10 m. Models with depth alone and with depth plus hook-position group were each tested against the model without depth by likelihood-ratio test, with Holm adjustment across the four species. These models describe species share among fish caught, not CPUE or capture probability. Binomial models were used because they had lower AIC than beta-binomial models (the OTHR beta-binomial model did not converge) and showed no overdispersion (*DHARMA*).

The effect of hook-position group on species share was tested post hoc in the same way, and modelled shares with 95% confidence intervals were obtained with *emmeans*. This analysis is exploratory. The significance level was 0.05.

3. Results

Observed hook depths were shallower than theoretical depths in 82 of 100 records (Fig. 1). Mean observed depth was 71.0 m (SD 17.7 m) against 87.1 m theoretical (root mean square error 23.6 m), and the estimated mean bias was -16.7 m (95% CI -23.2 to -10.2 m; $p < 0.001$), about 18% of theoretical depth. Most variation was among dates (SD 12.2 m), with 2.5 m among sensors and 12.3 m residual. Bias was negative in every hook-position group (Table 1, Fig. 2) and did not differ significantly among groups ($\chi^2 = 5.73$, 3 df, $p = 0.125$; pairwise Tukey $p \geq 0.158$). Theoretical depth rose from 77.0 m at hooks 1,8 to 92.6 m at hooks 4,5, whereas observed depth rose from 62.9 m to 73.1 m at hooks 2,7 and then stayed at 72–74 m.

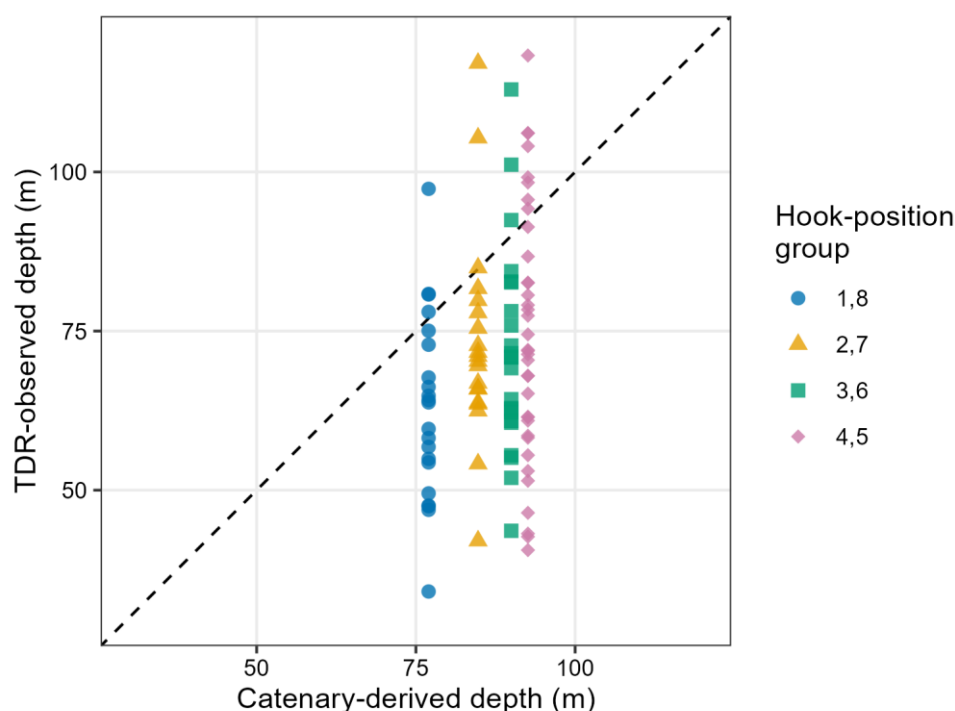


Figure 1. TDR-observed hook depth against catenary-derived depth (n = 100). The dashed line shows equality; colours show hook-position groups.

Table 1. Observed and theoretical hook depth (m) by hook-position group. Bias is observed minus theoretical depth. Model-adjusted bias is from a mixed model with a date random intercept (95% confidence interval).

Hook group	n	Observed mean (SD)	Theoretical mean	Mean bias	Model-adjusted (95% CI)	bias
1,8	21	62.9 (14.6)	77.0	-14.1	-14.5 (-22.1, -7.0)	
2,7	20	73.1 (16.3)	84.8	-11.7	-11.8 (-19.4, -4.1)	
3,6	23	71.5 (16.1)	90.0	-18.4	-18.8 (-26.2, -11.4)	
4,5	36	74.3 (20.0)	92.6	-18.3	-19.1 (-26.0, -12.3)	
All	100	71.0 (17.7)	87.1	-16.1	-16.7 (-23.2, -10.2)*	

*Overall estimate from the model with date and sensor random intercepts.

The 62 positive-catch records contained 195 fish: 74 YFT (38%), 65 SWRD (33%), 28 SAIL (14%) and 28 OTHR (14%) (Table 2). The binomial models showed no overdispersion and all converged. After Holm correction, observed depth was not significantly associated with the share of any species in either model set (Table 3). Swordfish gave the strongest signal (OR 1.38 per 10 m, 95% CI 1.02–1.87; $p = 0.045$; Holm $p = 0.18$), which weakened when hook-position group was included (OR 1.33, 95% CI 0.99–1.80; $p = 0.072$). Confidence intervals were wide for all species.

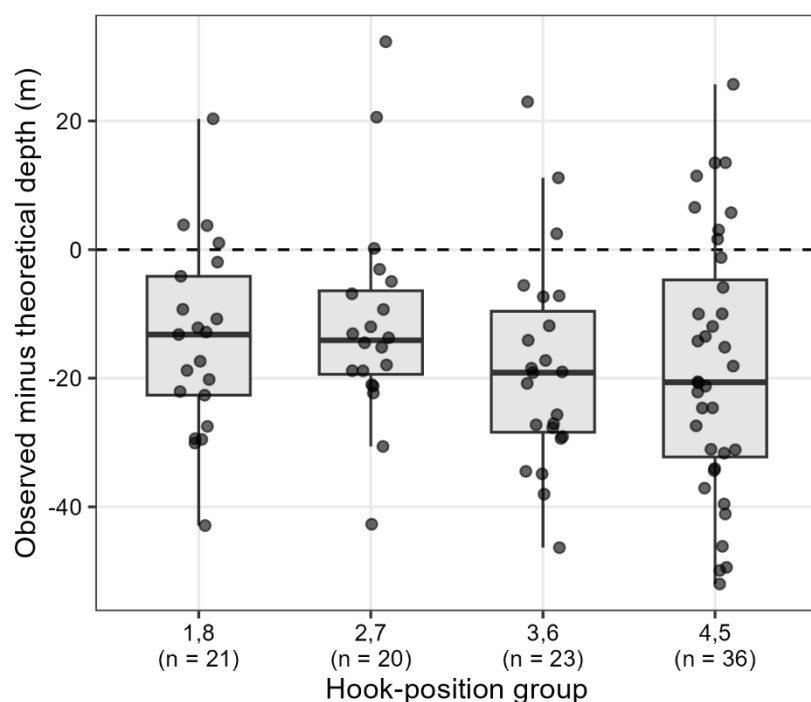


Figure 2. Observed minus theoretical hook depth (m) by hook-position group. The dashed line is zero bias.

Table 2. Catch of the 62 positive-catch records by hook-position group: number of fish (pooled percentage of the group's catch).

Hook group	Records	Observed depth, mean (SD) m	Fish	YFT	SWRD	SAIL	OTHR
1,8	15	66.7 (14.3)	39	13 (33)	7 (18)	12 (31)	7 (18)
2,7	17	73.6 (17.5)	54	19 (35)	14 (26)	8 (15)	13 (24)
3,6	15	74.7 (19.0)	50	19 (38)	20 (40)	6 (12)	5 (10)
4,5	15	73.2 (14.6)	52	23 (44)	24 (46)	2 (4)	3 (6)
Total	62		195	74 (38)	65 (33)	28 (14)	28 (14)

Hook-position group was associated with species share for SAIL ($p = 0.016$), OTHR ($p = 0.033$) and SWRD ($p = 0.047$), but not YFT ($p = 0.66$). None remained significant after Holm correction (adjusted $p = 0.064$ – 0.100). Modelled swordfish share rose from 18% (95% CI 7–38%) at hooks 1,8 to 47% (28–67%) at hooks 4,5, while sailfish share fell from 27% (13–46%) to 4% (1–14%) (Fig. 3). OTHR share was highest at hooks 2,7 (24%) and lowest at hooks 4,5 (6%), and yellowfin share changed little (22–31%). Intervals for neighbouring groups overlapped for all species. Modelled shares apply to a typical date and were fitted separately for each species, so they do not sum to 100% and differ from the pooled percentages in Table 2.

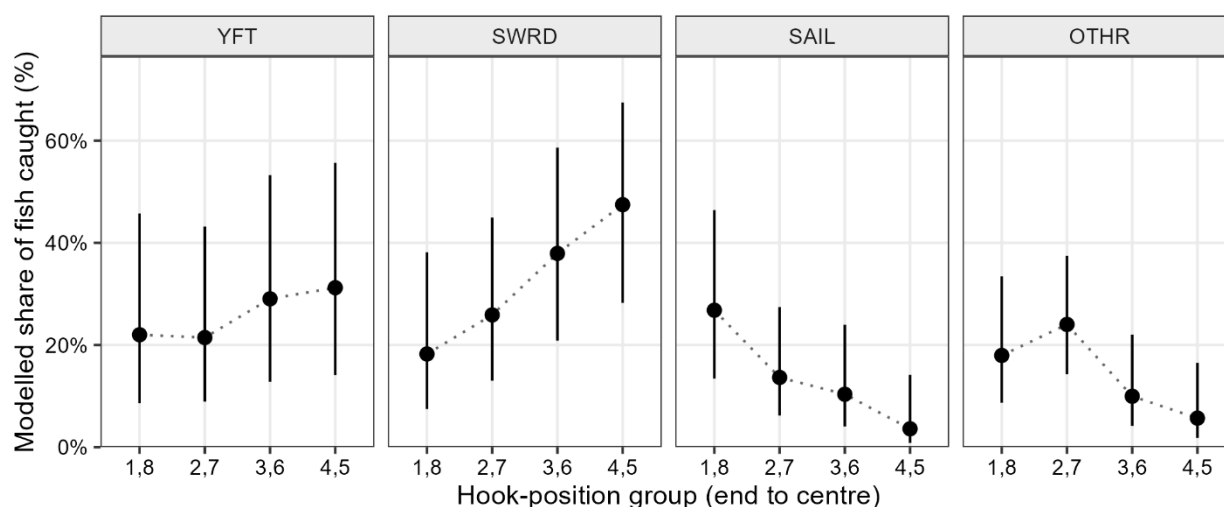


Figure 3.

Modelled share of fish caught (95% CI) by hook-position group for each species, from binomial mixed models with a date random intercept.

Table 3. Odds ratios (95% CI) per 10 m increase in observed depth for the share of each species among fish caught (binomial GLMM, date random intercept; n = 62 records, 19 dates). p is the likelihood-ratio test; Holm p is adjusted across the four species.

Species	Depth only: OR (95% CI)	p	Holm p	Adjusted for hook group: OR (95% CI)	p	Holm p
YFT	0.78 (0.55–1.10)	0.174	0.52	0.74 (0.52–1.05)	0.110	0.33
SWRD	1.38 (1.02–1.87)	0.045	0.18	1.33 (0.99–1.80)	0.072	0.29
SAIL	0.93 (0.62–1.41)	0.739	0.81	1.12 (0.79–1.57)	0.539	0.69
OTHR	1.11 (0.87–1.43)	0.406	0.81	1.13 (0.88–1.47)	0.346	0.69

4. Discussion

Hooks were on average 16.7 m (about 18%) shallower than the catenary predicted, and were shallower in four of five records. Errors for individual hooks were large (root mean square error 23.6 m) and went in both directions, so a single correction factor would not fix them. Bias was similar at all hook positions, so the discrepancy affects the whole basket. Most variation was among dates (SD 12.2 m) rather than sensors (2.5 m), which points to day-to-day conditions such as current and setting speed. Bach et al. (2008) tested sag ratio, mainline length per basket, setting bearing, wind stress, and current velocity and shear as drivers of longline shoaling.

This study cannot identify the cause. The line may sag less than the assumed sag ratio of 0.85, or the sensor position may play a role. Back-calculating the sag ratio that reproduces the observed depth for each date would be a useful next step with collecting additional data of distance between two buoys.

The depth profile along the basket was also flatter than predicted. The catenary puts central hooks 15.6 m deeper than end hooks, but observed depth rose by about 10 m and then stayed at 72–74 m. Bias was somewhat larger at the central hooks, but not significantly so ($p = 0.125$). With 100 records the test had limited power, so no difference was detected, which is not the same as none existing.

Observed depth in metres did not explain species share once multiple testing was accounted for. Swordfish was the only nominal signal. Mean depth differed little among hook groups (63–74 m) compared with variation within groups

(SD 14–20 m), and there were only 62 records, so depth effects were hard to detect and the confidence intervals were wide.

Hook position was more informative, although exploratory. From the end hooks to the central hooks, swordfish share rose and sailfish share fell, and yellowfin share stayed similar. This fits the vertical habitats of these species, with sailfish near the surface and swordfish in deeper water (Braun et al., 2015; Hoolihan, 2005). None of the group tests remained significant after Holm correction, so these results are hypotheses. Hook position may also act through factors other than depth, such as distance from the buoy line or the order of setting, and this study cannot separate them.

Hook depth should be measured, not assumed. The catenary calculation would place hooks about 17 m too deep on average, by different amounts on different days, which matters when stratifying effort or standardising CPUE (Bigelow et al., 2002). The analysis describes species share among fish caught, so it cannot show how catch rates change with depth. A CPUE analysis would need all hooks, including those that caught nothing.

The experimental gear (float line 14.0 fathoms, branch line 23.5 fathoms, 26 fathoms between branch lines) was close to the fleet median (15, 23 and 27 fathoms). Fourteen of 27 surveyed vessels (52%) used similar dimensions, including 8 of 9 from Negombo and all five from Dikowita, but only one of eight from the Matara area (Dondra, Kottegoda and Nilwala) and none of five from Beruwala. The results are therefore most relevant to Negombo and Dikowita gear. Bait also varied among vessels and may influence catch composition.

All data came from a single vessel operated between December to June closer to South coast of Sri Lanka. The sample was small and clustered by date (71 matched records, 62 with catch), and observed depth was a mean for each deployment, so it does not show depth variation during the soak. Zero-catch records were excluded, so the results apply only to hooks that caught fish, and the OTHR group may hide species with different depth preferences. The hook-position analysis was post hoc and none of its effects remained significant after Holm correction.

5. Conclusions

On a single vessel, catenary-derived hook depths overestimated observed depths by about 17 m on average, with large variation among dates and no detectable difference among hook positions. The gear was typical of about half of the surveyed fleet. Observed depth in meters was not significantly associated with species share once multiple testing was accounted for. Exploratory results suggest that swordfish share increases and sailfish share decreases from the end hooks to the central hooks, whereas yellowfin share is similar along the basket, and these patterns need confirmation with more records. The results support measuring hook depth directly, rather than assuming it, when describing fishing effort and catchability in tuna longline fisheries.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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