Longline sink rate verification

Draft Report

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Background

Sinking baited hooks to depth quickly, and underneath an effective tori line, is one of the most widely accepted and well-regarded methods of reducing seabird bycatch in both pelagic and demersal longline fisheries (ACAP 2019a and b).

Longline sink profiles constructed from data collected using Zebra Tech Wet Tag time depth recorders (TDRs) have shown that these particular recorders have limitations, particularly around recording the time that tags leave the vessel and the variable delay in recording after immersion in seawater. Conducting paired deployments with more accurate, but less 'user friendly', TDRs provides for assessment of the accuracy and suitability of Wet Tag data for estimating sink profiles and hook depths at given distances behind the vessel.

Hook sink profiles generated from TDR data need to be reliable, and comparable to bottle test data in order to reliably inform fishers of the depth of hooks at different distances astern. This data is particularly useful with respect to mitigation standards for demersal longliners (MPI, 2019).

Objective

Compare sink rate profiles of Zebra Tech Wet Tags and bottle tests against CEFAS and Star Oddi TDRs.

Time depth recorders

Time depth recorders use an internal clock, a pressure sensor, a temperature sensor, and a data logger. The temperature reading is used when converting pressure readings to depth either onboard the recorder, or post-hoc on a PC.

Pressure sensor response time is fast and temperature sensor response is somewhat slower. Consequently, when the air is at a different temperature to the water, immediately after immersion the temperature reading is not correct and contributes to errors in calculated depth. These errors can be minimised by using pressure sensors that are not sensitive to temperature, storing TDRs in a bucket of water, the same temperature as the seawater, prior to deployment and/or substituting the erroneous temperature readings during processing.

Further errors in calculated depths are caused by pressure differences behind the boat as water rushes in to fill the 'hole' left by the boat, and by pressure waves coming off the propellor.

Swell and wind driven waves provide further variation, essentially varying the sea surface height below which depth is measured. The obvious example of this is a longline backbone entering the face of a wave and then emerging at the back of the wave.

Time depth recorders have been used to generate sink profiles and asses the risk posed to seabirds by different longline configurations, both internationally and within New Zealand (e.g. Goad et al., 2010, Goad 2011, Goad et al., 2019, Pierre et al, 2013, Pierre et al., 2015, Robertson et al., 2013, Santos et al., 2019). In summary this work has suggested minimising time to depth by adding weight in the snood, as close to the hook as possible, for pelagic longlines, and adding weight to the backbone, either internally or externally, at closely spaced regular intervals for demersal longlines. Typically, this work has focused on comparing different weighting treatments and examining differences in sink rate, rather than absolute depth at time measurements.

Bottle tests have been routinely used by demersal longliners fishing in CCAMLR waters to verify compliance with conservation measure 24-02 (2004), which specifies a sink rate of 0.3 m/s. Tests involve clipping a bottle onto the longline via a length of rope wound around the bottle. As the longline sinks the rope unwinds, and at a depth equal to the length of rope, the bottle is pulled underwater. Measuring the time taken for the bottle to be pulled under allows calculation of an average sink rate to a depth equal to the length of rope.

The introduction of mitigation standards in New Zealand (MPI, 2019) has resulted in increased scrutiny of demersal longline sink rates. Verification of meeting the demersal longline standards requires an absolute measurement of whether the longline is below either five or ten metres by the end of the tori line, using a bottle test.

TDR specifications

Three types of recorders were employed (Figure 1) and they are briefly described below:

CEFAS TDRs have a published accuracy of +/- 5 m and resolution of 15 cm, weigh 2.5 g in seawater and measure 36.5 mm in length by 12 mm diameter. They were set to record continuously every 0.1 seconds. Temperature response to 63% (of the temperature difference) is quoted as 47 seconds, and pressure response is not specified but appears to be fast. Data processing is 'onboard' so a single file is produced with calculated depths.

Star Oddi TDRs have a published accuracy of +/- 4.8 m and resolution of 24 cm, weigh 12 g in seawater and measure 46 mm in length by 15 mm diameter. They were set to record continuously every second. Temperature response to 63% is quoted as 20 s, with 'immediate' pressure response. Data processing is post collection and largely controllable, with the ability to manually input correction factors. Notably Star Oddi were able to add an option for substituting temperatures used to correct pressure readings.

Wet Tags have a published accuracy of +/- 1.5m, weigh 30 g in seawater and measure 108.5 mm in length by 39.5 mm diameter. They recorded every five seconds, starting once they have registered a published trigger depth of 1.5 m. Data processing is onboard.

Figure 1. Photograph showing (from left to right) Wet Tag, Star Oddi TDR, CEFAS TDR, Wet tag, NFC tag, and housing for CEFAS TDR as deployed on the demersal longlines, and two Star Oddi housings used for paired deployments on the demersal longlines.

Data sets

This report summarises four sets of data:

1. Star Oddi TDR, CEFAS TDR, and Wet Tag data collected opportunistically on a pelagic longline vessel, when conducting sea time for contract 18302 MIT2018-02.

Following this trip contract BCBC202011c was developed to collect further sets of data, to compliment project MIT 2018-03:

2. Free fall tests of the sink rate of different pelagic longline branchline configurations, conducted on two trips from stationary vessels in sheltered water.

3. Star Oddi TDR, CEFAS TDR, Wet Tag and bottle test data collected on a demersal longliner targeting snapper and tarakihi, as part of normal fishing operations.

4. Star Oddi TDR, CEFAS TDR, and Wet Tag data from controlled drops to different depths.

Methods

Pelagic longline fishing trip

A single trip of six sets was undertaken on a 22 m steel pelagic longliner fishing for southern bluefin tuna at "The Gables", south of East Cape.

Gear setup

Hookpods were attached to all snoods at 1.0 – 1.2 m from the 16/0 circle hook. Snoods were two-millimetre diameter monofilament nylon, 7-10 m in length, and hooks were baited with small whole squid. Approximately twenty percent of snoods had 60 g weighted swivels at the clip. Float ropes were a variety of lengths, with most close to 13 m. Basket arrangement was a repeated sequence of surface float, 10 hooks, surface float, 10 hooks, 150 mm diameter pressure float on a snood, 10 hooks. Lines were set without a shooter from a free-spooling drum at 6.5 knots, generally into short 2.5 – 4.0 m seas and 15 – 35 knots of wind. Overall gear and conditions were typical of the winter bluefin fishery.

Recorder deployment.

CEFAS and Starr Oddi TDRs were attached to new 10 m snoods, 0.5 m from the hook, and hooks were baited with whole squid and deployed singly as part of normal fishing operations. Single deployments were either at 'snood one', immediately after a float, or at 'snood five', mid basket after a surface float. CEFAS TDRs were configured with a wet switch to initiate 'fast log' sampling every 0.1 seconds, from 0 – 20 m depth.

Wet Tags were attached on the end of 10 m snoods, without a hook or Hookpod and all deployed at 'snood five', by the skipper, again as part of normal fishing operations. CEFAS TDRs were attached to the snood immediately above all Wet Tags. On two sets Star Oddi TDRs were also attached.

The time that snoods with TDRs attached were clipped onto the mainline was recorded on a digital watch, and synchronised to a PC which was used to program and download both CEFAS and Star Oddi TDRS. Times were recorded to the nearest half-second and where 'water entry time' of the TDR was noticeably different to 'clip-on time' this was also noted. The watch was also synchronised with the phone used to download Wet Tag data.

In summary CEFAS and Star Oddi TDR 'single' deployments approximately measured the sink rate of the baited hook whereas Wet Tags were initially measuring the sink rate of the Wet Tag on a plain snood.

Free fall tests using pelagic longline snoods

A set of five snoods were made using 13 m lengths of 2.0 mm diameter monofilament and 16/0 circle hooks baited with whole squid. A series of deployments beside a stationary vessel were conducted. Snoods were clipped onto a line onboard the vessel which held the clip at water level. The snood was fed overboard to remove loops or tangles and then TDRs, hooks and baits were cast approximately two metres outward from the vessel.

Near field communication tags were attached to all Wet Tags and these were scanned prior to casting the snood. The time TDRs hit the water was recorded on paper, from a mobile phone. A GoPro camera was set up to record a view of the mobile phone time and the casting of snoods, to act as a time check.

TDRs were stored on snoods in buckets of water prior to deployment, and between deployments, to minimise the temperature difference before and after deployment. Water in the buckets was refreshed between treatments.

The following snood configurations were tested, in seawater, with five repeats of each treatment, using different snoods and TDRs for each repeat:

Wet Tag on the end of a snood
Wet Tag and Star Oddi TDR on the end of a snood
Wet Tag and CEFAS TDR on the end of a snood
Wet Tag and CEFAS and Star Oddi TDRs on the end of a snood
Wet Tag 0.5m from a baited hook
Star Oddi TDR 0.5m from a baited hook
CEFAS TDR 0.5m from a baited hook
Wet Tag, CEFAS and Star Oddi TDRs 0.5m from a baited hook

Following the analysis of these results a second trip, in freshwater, tested the following configurations, with ten repeats conducted for each treatment (by deploying each snood twice):

CEFAS TDR 0.5 m from a baited hook, 40g lead at hook:
Wet Tag and CEFAS TDR 0.5 m from a baited hook, 40g lead at hook
CEFAS TDR 0.5 m from a baited hook, unweighted snood
Wet Tag and CEFAS TDR 0.5 m from a baited hook, unweighted snood
CEFAS TDR 0.5 m from a baited hook, hookpod at 2 m
Wet Tag and CEFAS TDR 0.5 m from a baited hook, hookpod at 2 m

Demersal longline fishing trip

Gear setup

A single trip was undertaken on a demersal longliner targeting snapper and tarakihi in the Bay of Plenty. Recorders were attached to the longline in pairs, with Star Oddi TDRs and CEFAS TDRs together, and Wet Tags and CEFAS TDRs together. CEFAS TDRs were also attached to the clip of a bottle test, which comprised of a 330 ml plastic bottle and a five-metre length of rope. Recorders and bottle tests were clipped directly to the longline in place of a snood or onto floats. Three positions on the longline were sampled: on a dropper (weight-float combination), half way after a dropper, and three quarters of the way after a dropper.

Recorder deployment

TDRs were programmed on the same PC and clocks were synchronised between the PC, the tablet used to download Wet Tags, and a mobile phone. Go Pro video footage was used to capture the mobile phone clock and the setting operation. TDRs were stored in a bucket of seawater collected before the start of the set and removed just before clipping onto the longline. Clip-on times were recorded from the phone clock and water entry times were also recorded when possible. Bottles were monitored using reflective tape and a spotlight from deck level, with the time the bottle was last visible recorded.

Controlled drops

Eight Wet Tags, three CEFAS TDRs and three Star Oddi TDRs were held at approximately one metre depth for five minutes to allow the recorders to reach water temperature. Three controlled drops were then made to the sea bed (5.15m depth), stopping at one, two, three, and four metre depths for thirty seconds on the way up and down. Depth changes took two to three seconds, and started every 30 s. Following the controlled drop three more rapid drops were conducted to the sea bed. Depths were measured using the length of the rope recorders were suspended from.

TDR data processing

Offsets were applied to CEFAS and Star Oddi TDR records on a set-by-set basis for the fishing trips and on a daily basis for the free fall tests. Offsets were calculated using depth readings averaged over a minute during the period of stable temperature readings. This was usually a minute prior to deployment but for the controlled drops depth readings after the first drop were used. Wet Tags all read zero after recovery during free fall tests, so records were not adjusted after the free fall tests.

Temperature corrections were applied to Star-Oddi TDR pressure records to cover the period during which TDR temperature sensors were acclimatising to sea water temperature. Temperature profiles were analysed to estimate surface seawater temperature and the data was re-processed using the Sea Star software package with substituted temperature values immediately after deployment. CEFAS TDR data were corrected on the same per deployment or per day basis by applying a pressure offset in excel. Offsets were calculated using the average depth recorded over 60 readings finishing one minute prior to initial deployment. Temperature correction was not possible for the CEFAS TDRs as they converted pressure and temperature to 'depth' on the fly and were not able to have post collection processing applied.

For the fishing trips, corrected results were compiled by set in excel and plots of each deployment were produced. Mean depths (+/- standard deviation) at time were calculated, by treatment and recorder type, using only data from paired deployments. In a similar manner the mean time to five metres depth was calculated.

For the free fall data, plots of each TDR deployment were examined for periods of linear sink rate and then a sink rate was calculated for each deployment, using simple linear regression. Summary tables were produced to describe the average sink rates per treatment (+/- standard deviation).

Results

Pelagic longline fishing trip

On two occasions the times recorded by the wet switches on the CEFAS tags were earlier than 'clip-on' times recorded on the watch but otherwise times matched within two seconds and most were within a second.

Paired deployments of CEFAS and Star Oddi TDRs lined up reasonably well (Figure 2).

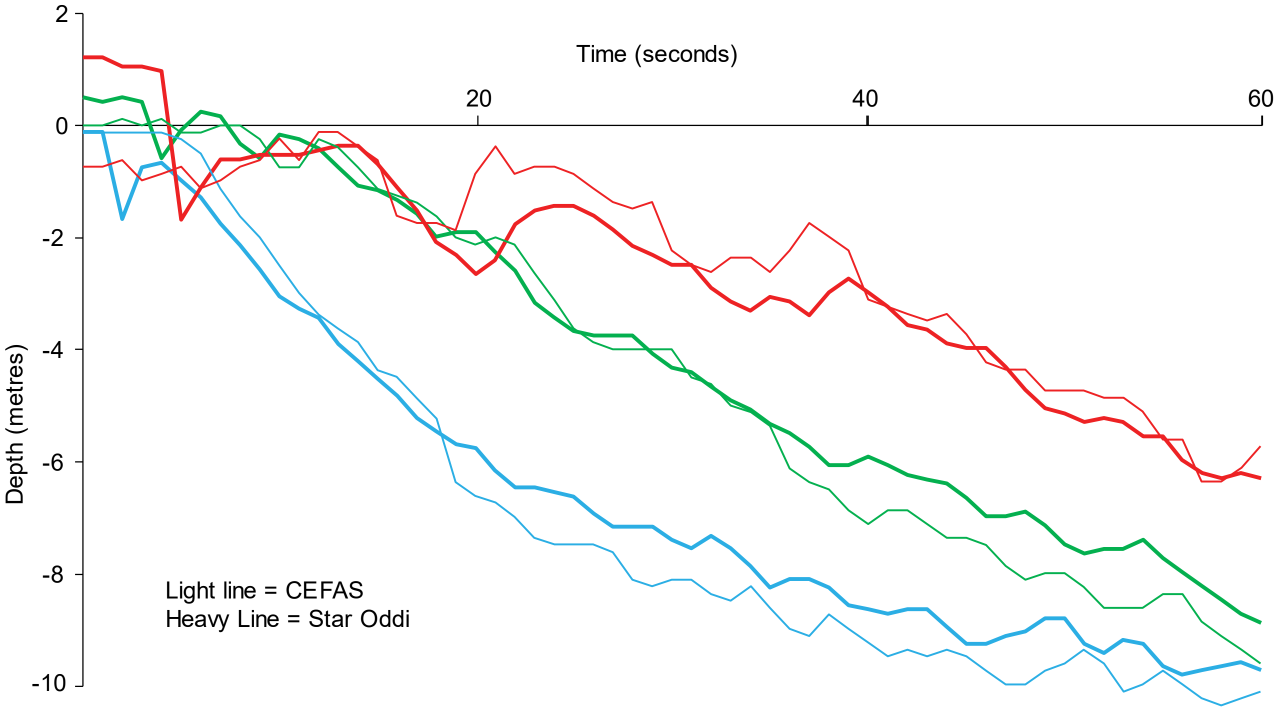
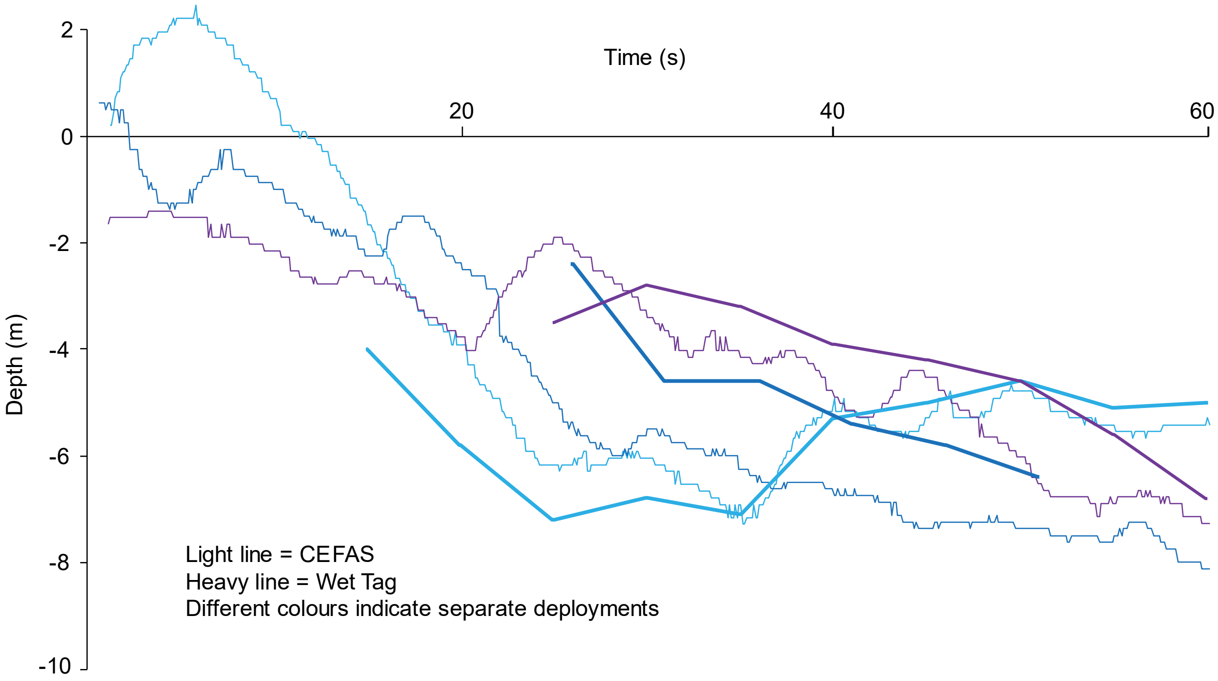


Figure 2. Paired deployments of Starr Oddi and CEFAS TDRs deployed with a Zebra Tech TDR on a 10 m snood. Pairs are in the same colour.

Paired deployments of CEFAS TDRs and Wet Tags also lined up reasonably well, although the Wet Tags took some time to switch on and initial readings were up to two metres different from CEFAS TDRs. With the CEFAS TDRs set at fast sample rate it is clear that a lot of the 'noise' is attributable to swell (Figure 3).



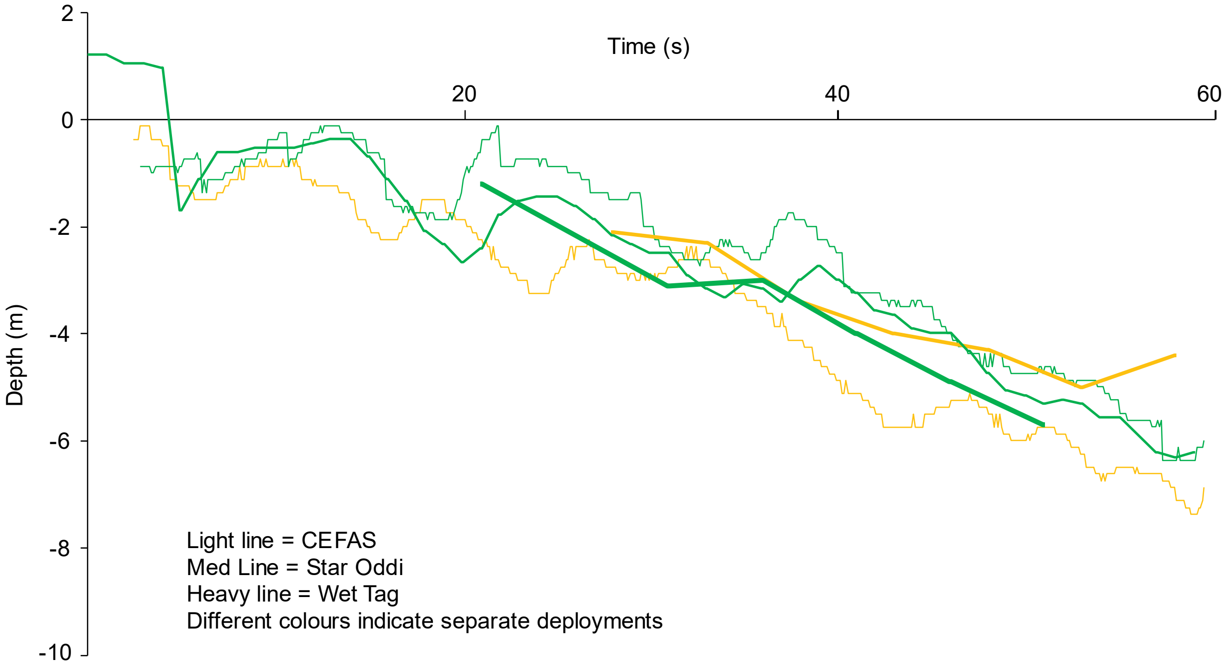


Figure 3. Paired deployments of CEFAS and Wet Tags with separate plots for separate sets.

The position of the snood in the basket did not appear to influence sink rates (Figure 4).

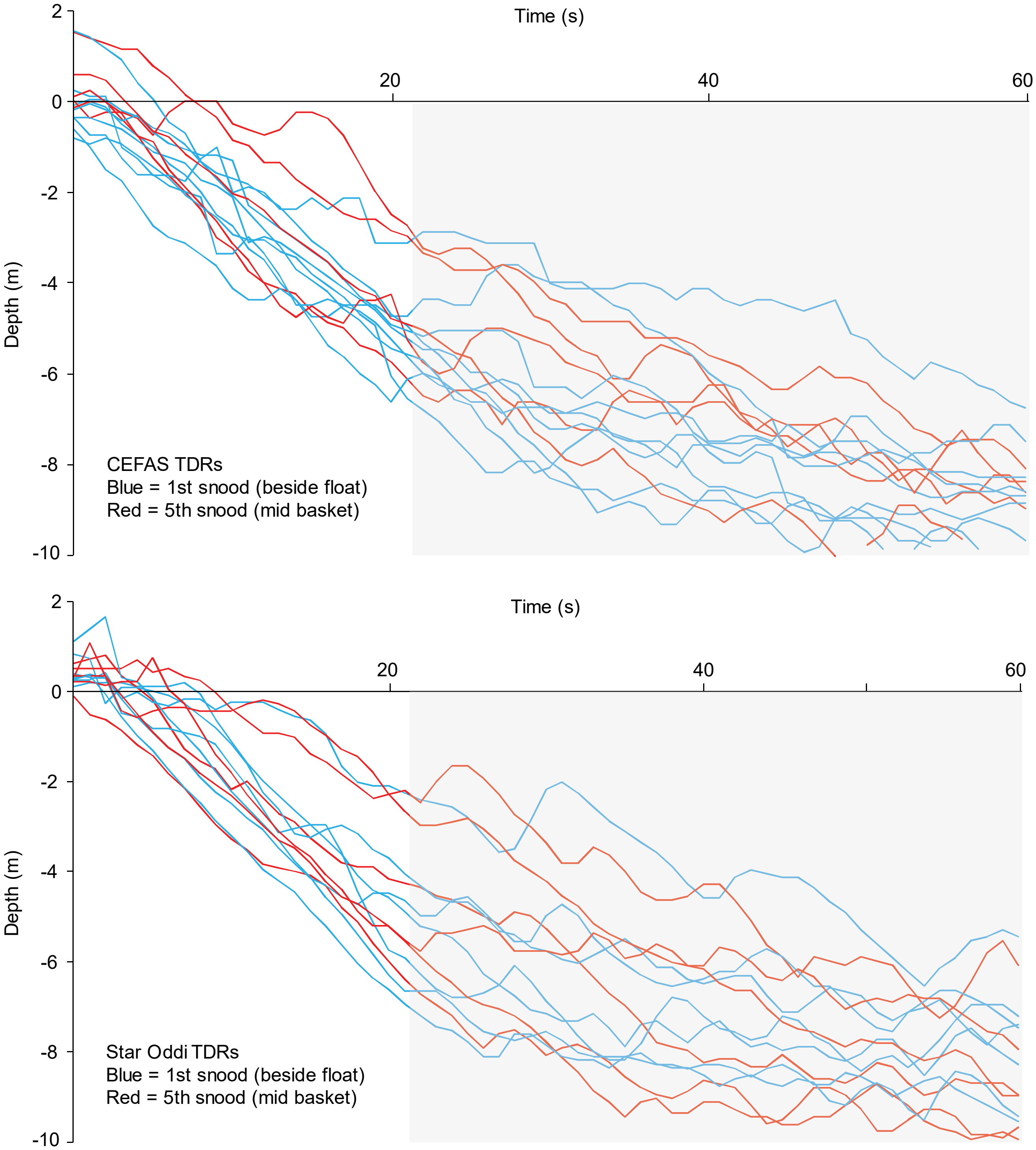


Figure 4. Single deployments of CEFAS and Star Oddi TDRs at different basket positions. Shaded area is beyond 75 m astern.

Comparing single deployments of CEFAS and Star Oddi TDRs above baited hooks with Zebra Tech TDRs on a plain snood shows that Wet tags sink slower than longline hook, and that it would be challenging to estimate the time Zebra Tech TDRs leave the vessel and estimate initial sink profiles under the tori line (Figure 5).

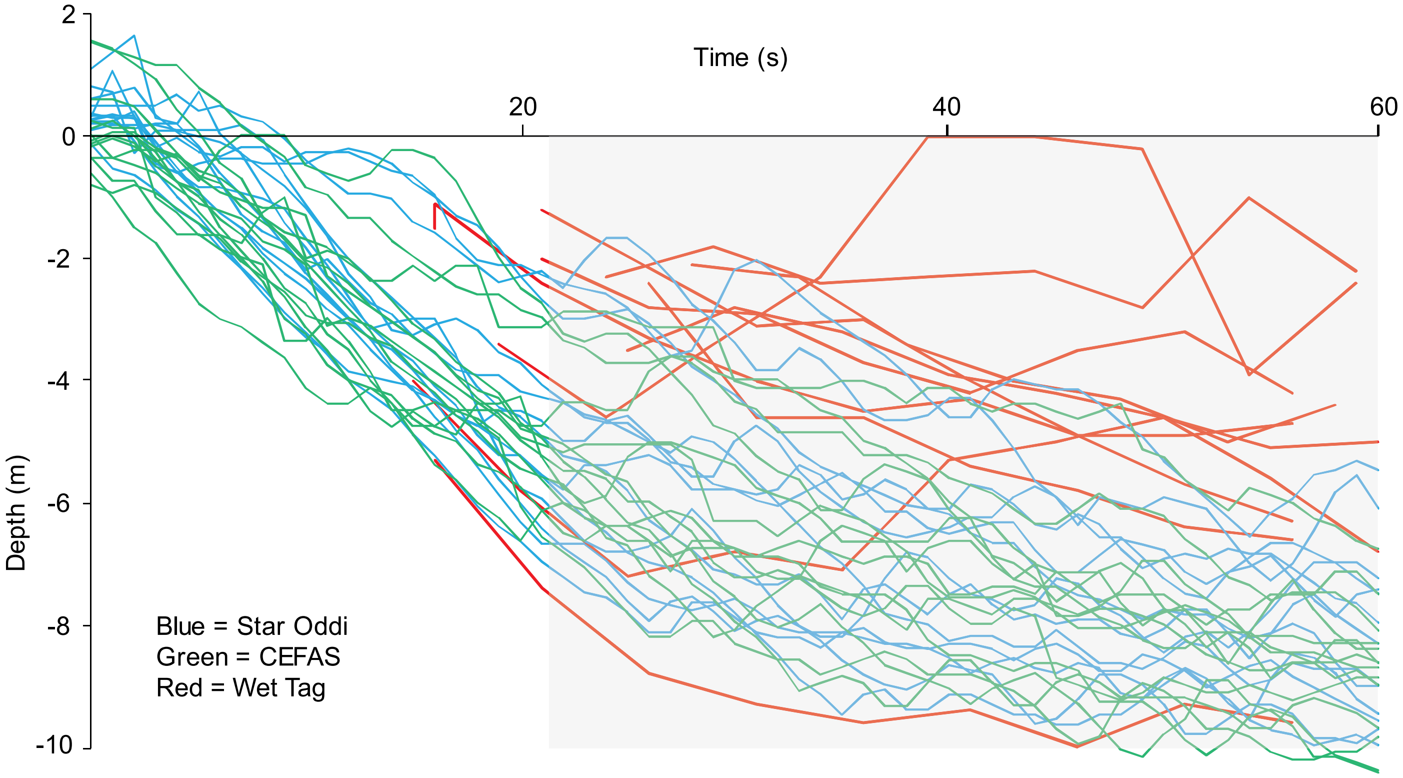


Figure 5. Single deployments of CEFAS and Star Oddi TDRs positioned 0.5 m from a baited hook, and Wet Tags deployed on a plain snood. Shaded area is beyond 75 m astern.

Surprisingly, the heavier Starr Oddi tags (12 g) produced similar sink profiles to the CEFAS tags (2 g), with similar variation but slightly shallower depths in the first 20 seconds (Figure 6).

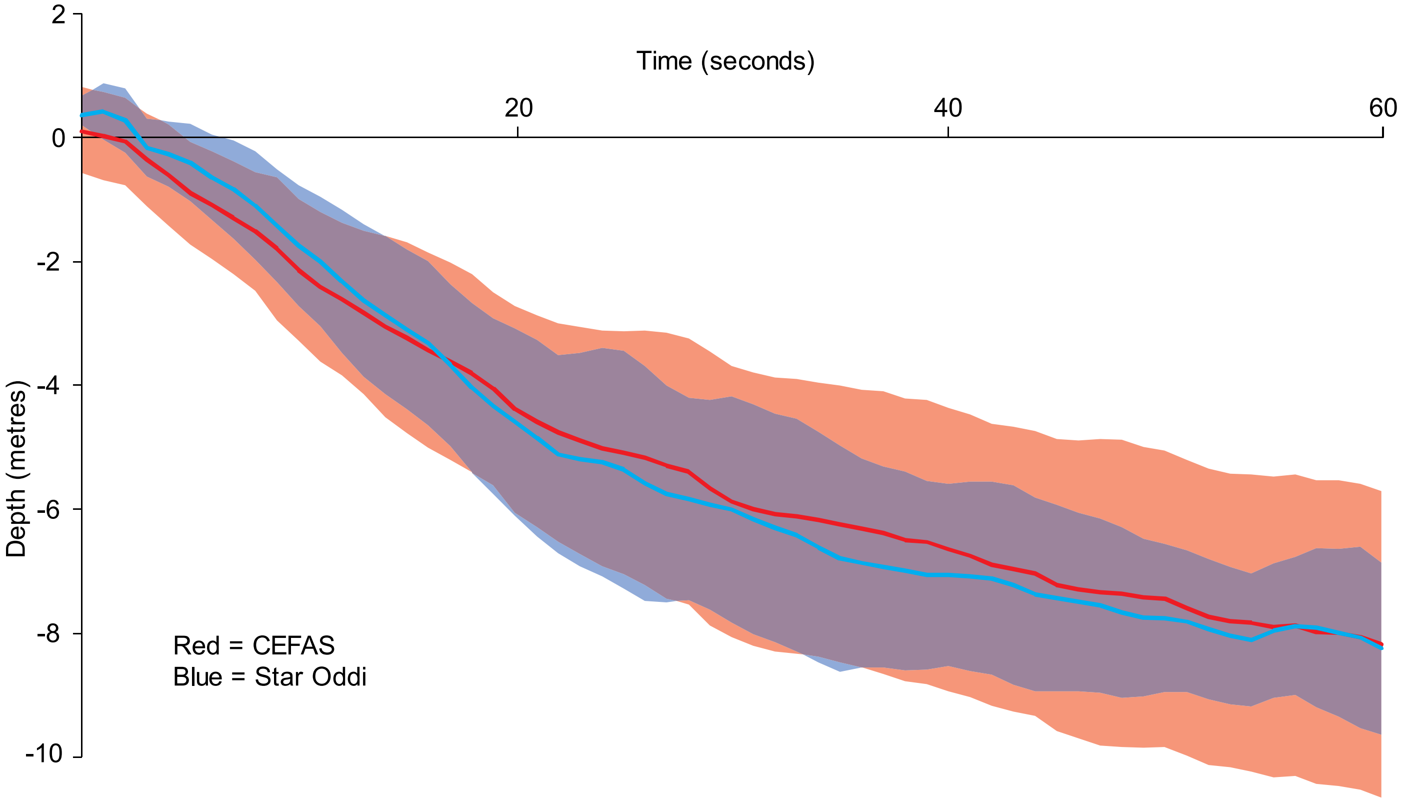


Figure 6. Mean depths at time for single deployments of CEFAS and Starr Oddi TDRs. Shaded areas show +/- standard deviation.

Free fall tests

Near field communication tags typically took one to two seconds to register and delays between scan time and recorded water entry time were consistent within trips, at two seconds during trip one and three to four seconds during trip two.

TDRs all sank with an approximately linear profile for at least eight metres, with sink rates then decreasing as the snood came tight and the TDR swung directly under the vessel. Hookpod snoods settled at shallower depths, as the snood was effectively two metres shorter. No Hookpods opened. Weighted snoods typically sank to depth within 20 seconds, whereas unweighted and Hookpod snoods took in the order of 25 seconds. Some exceptions were apparent, especially in data collected at sea during the first trip. These were related to drift of the vessel, tide, tangles, and fish taking baits.

Star Oddi TDRs had more drift in the internal clocks than CEFAS TDRs, and Wet Tags had more drift again, and would potentially benefit from application of negative pressure offsets. One Wet Tag did not appear to record any data.

Wet Tags on the end of a hookless snood sank at a similar rate to unweighted hooks (Table 1). When added to a normal snood Wet Tags were capable of distinguishing the sink rate of different snood configurations but tended to slow the sink rate of, particularly, weighted hooks (Figure 7, Table 2). Sink rates calculated from Wet Tags were consistently slower than those calculated from CEFAS and Star Oddi TDRs, on the same snood (Table 2). Using just the first two records from Wet Tags improved estimates of sink rate, and generally increased estimated sink rate, as in some cases the snood was tight and sink rates were slower by the third reading (Tables 2 and 3). Wet Tag readings were closer to CEFAS TDRs on slower sinking snoods configurations. The first recorded depth from Wet Tags varied between 2.8 and 6.5 m, with an average of 4.6 m (Figure 7).

Table 1. Summary of sink rates (plus and minus standard deviation) recorded during trip one.

Treatment	Wet Tag (3 points)	Wet Tag (2 points)	Star Oddi	CEFAS
Wet Tag on the end of a snood	0.35 (0.21- 0.49)	0.38 (0.24- 0.52)		
Wet Tag and Star Oddi TDR on the end of a snood	0.43 (0.4- 0.46)	0.48 (0.39- 0.57)	0.46 (0.41- 0.51)	
Wet Tag and CEFAS TDR on the end of a snood	0.35 (0.28- 0.42)	0.39 (0.33- 0.45)		0.45 (0.39- 0.51)
Wet Tag and CEFAS and Star Oddi TDRs on the end of a snood	0.39 (0.22- 0.56)	0.41 (0.24- 0.58)	0.47 (0.43- 0.51)	0.44 (0.35- 0.53)
Wet Tag 0.5m from a baited hook	0.39 (0.34- 0.44)	0.38 (0.32- 0.44)		
Star Oddi TDR 0.5m from a baited hook			0.42 (0.33- 0.51)	
CEFAS TDR 0.5m from a baited hook				0.39 (0.27- 0.51)
Wet Tag, CEFAS and Star Oddi TDRs 0.5m from a baited hook	0.4 (0.35- 0.45)	0.4 (0.35- 0.45)	0.43 (0.4- 0.46)	0.45 (0.42- 0.48)

Table 2. Summary of sink rates (plus and minus standard deviation) recorded during trip two. Results from CEFAS TDRs include all 10 deployments, and just those with corresponding Wet Tag data (8 deployments). Wet Tag sink rates are shown using either the first two or first three data points after activation.

Treatment	CEFAS	Wet Tag (3 points)	Wet Tag (2 points)	CEFAS (same drops)
CEFAS TDR 0.5 m from baited hook, 40g lead at hook	0.63 (0.59 - 0.67)			
Wet Tag and CEFAS TDR 0.5 m from baited hook, 40g lead at hook	0.58 (0.51 - 0.64)	0.44 (0.36 - 0.52)	0.53 (0.44 - 0.62)	0.58 (0.52 - 0.64)
CEFAS TDR 0.5 m from baited hook, unweighted	0.46 (0.4 - 0.51)			
Wet Tag and CEFAS TDR 0.5 m from baited hook, unweighted	0.43 (0.4 - 0.46)	0.39 (0.35 - 0.44)	0.31 (0.14 - 0.48)	0.43 (0.39 - 0.47)
CEFAS TDR 0.5 m from baited hook, hookpod at 2m	0.41 (0.36 - 0.46)			
Wet Tag and CEFAS TDR 0.5 m from baited hook, hookpod at 2m	0.4 (0.35 - 0.45)	0.37 (0.33 - 0.41)	0.31 (0.14 - 0.48)	0.42 (0.38 - 0.46)

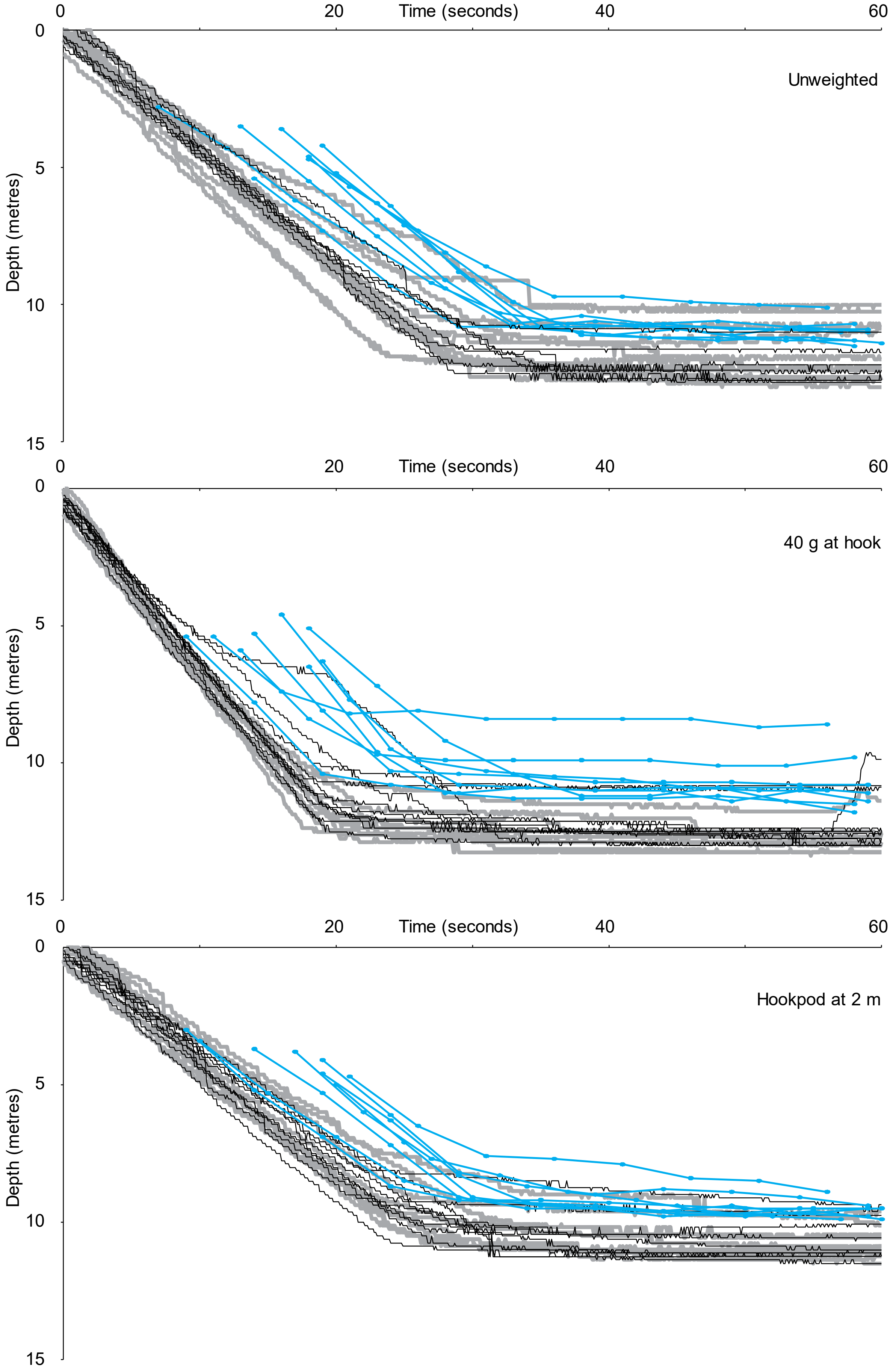


Figure 7. Time vs depth plots showing paired deployments of Wet Tags and CEFAS TDRS (blue and black lines) and single deployments of CEFAS TDRS (grey lines), for different snood configurations. All TDRs were placed at 0.5m from a baited hook.

Demersal longline fishing trip.

Trip summary

Three lines were set from a 17 m steel longliner working typical snapper gear. Hooks were Mustad 2020R, size 17, on 60 cm branchlines and stored on and set from 50 hook cards. Backbone was monofilament nylon with tied stoppers. 2.2 mm diameter backbone with 1.5 m stoppers (three metre hook spacing) was used for lines one and three, and droppers (3.2 kg steel weights with 1.5 – 4 m ropes and either 150 mm or 100 mm diameter pressure floats) were attached approximately every 25 hooks. A 3.3mm backbone with 1.0 m stoppers (two metre hook spacing) was used for line two. Droppers were attached every 50 hooks and halfway between droppers either two or three gillnet floats (55 mm diameter x 90 mm length) tied together were clipped directly to the line.

Hooks were baited alternately with squid and pilchard in a 1:1 ratio for all lines. Longlines left the vessel at a reasonably consistent 2.3 m height above sea level.

No birds were observed during line setting, though red-billed and black-backed gulls, black petrels, and flesh-footed shearwaters were present during all hauls, with four live flesh-footed shearwater captures during the trip. All were released swiftly by the crew.

TDR deployments

Twenty-four deployments were carried out on lines one and three, with a single pair of records incomplete on each line. Line two was shorter and set later than planned and so fewer TDRs were deployed, with three pairs incomplete (Table 3).

Table 3. TDR deployments for which records were recovered from both TDRs in the pair, by set and position on line.

Set	Dropper spacing (m)	Speed (knots)	Wet Tag and CEFAS			CEFAS and Star Oddi			CEFAS and Bottle
			dropper	1/2	3/4	dropper	1/2	3/4	1/2
1	75	6	0	4	4	3	4	4	4
2	100	4	2	3	3	1	2	2	0
3	75	6	2	3	3	3	4	4	4

TDRs placed at weights entered the water approximately two to three seconds after clip-on time, and sank in a roughly linear profile. TDRs at slowest sinking positions between weights entered the water 10+ seconds after clip-on time and initially sank slowly, until the following weight was clipped on, when sink rate gradually increased (Figure 8).

Star Oddi and CEFAS TDR paired deployments showed very similar profiles between pairs, with a reasonably consistent offset (Figure 8).

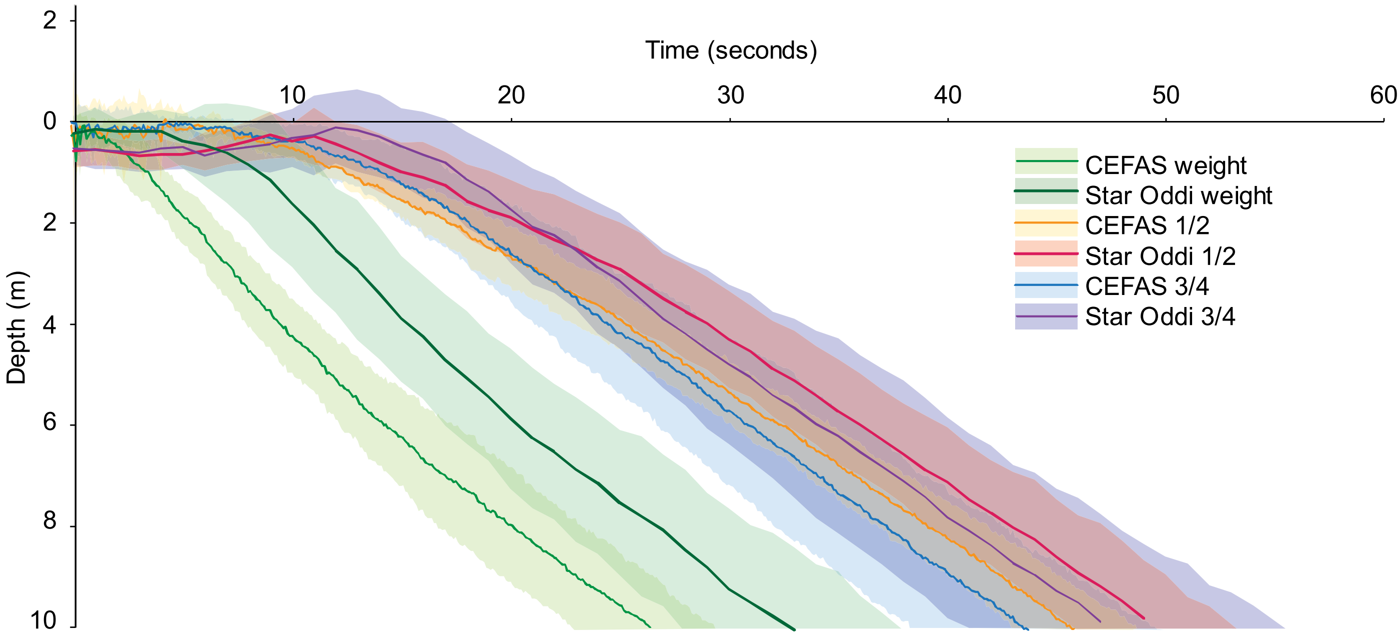


Figure 8. Mean sink profiles +/- standard deviation, for different line positions for lines one and three, by TDR type. Note only data from paired deployments is included.

Line two, with larger weight spacing, sank more slowly, and had a greater variation between line positions (Figure 9).

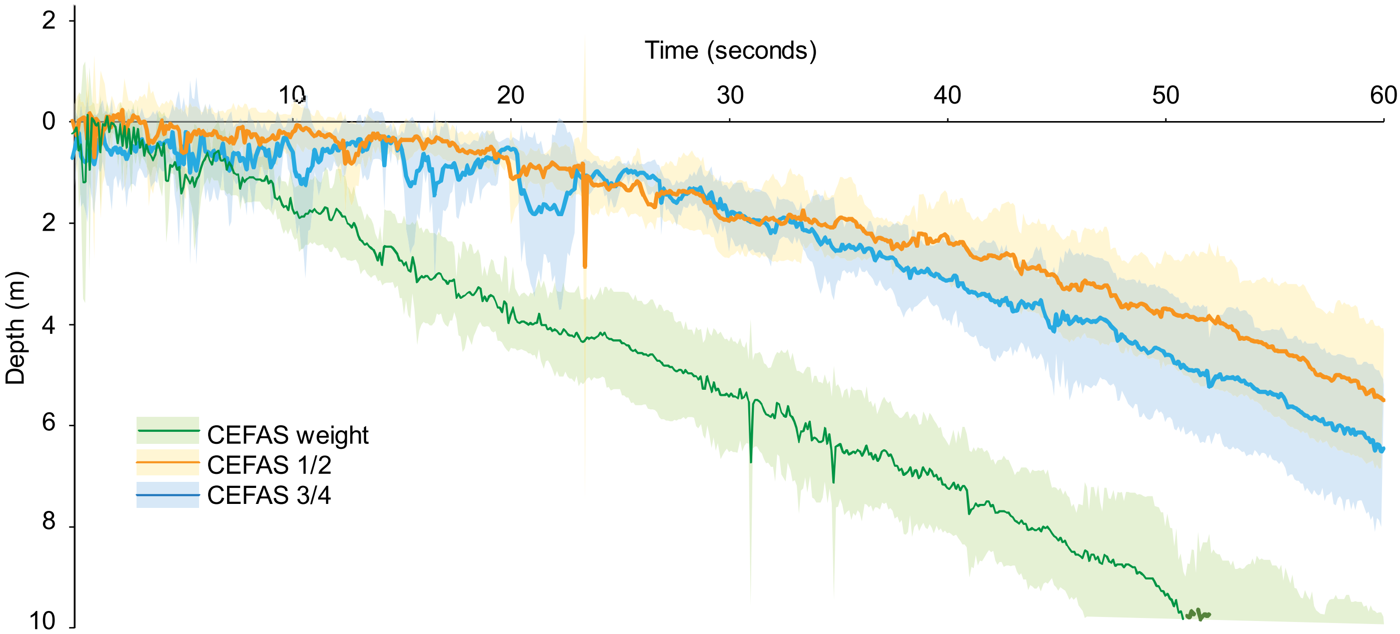


Figure 9. Mean sink profiles +/- standard deviation, for different line positions for line two. Note data is from CEFAS TDRs deployed with either a Wet Tag or a Star Oddi TDR.

Wet Tag data

During the trip a Moana Zebra Tech Tag went into low battery mode and attempted to continuously download data via bluetooth, preventing the vessels system from capturing Wet Tag data. After the trip, full data sets were recovered from four Wet Tags and data from set one were recovered from the other four Wet Tags. This reduced the sample sizes.

Wet Tags recorded few data points close to the surface, with a mean first depth of 3.9 m and a mean first record time of 29 seconds after leaving the vessel (Table 4).

Table 4. Time after clip-on and depth at which Wet Tags recorded their first reading. Position on line is shown for each deployment.

Set	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3
Time (s)	20	24	21	23	24	24	33	30	31	57	36	36	18	36	24	25
Depth (m)	4.3	5.6	3.5	3.7	3.5	3.8	4.5	3.5	3.0	2.7	2.9	2.1	3.0	9.1	2.3	4.1
Position	1/2	3/4	1/2	3/4	3/4	3/4	1/2	1/2	3/4	3/4	3/4	1/2	1/2	3/4	1/2	3/4

Wet tags did not start recording quickly enough to measure slower sink rates close to the surface and recorded depths more similar to CEFAS TDRs on the slower sinking line. (Figure 10).

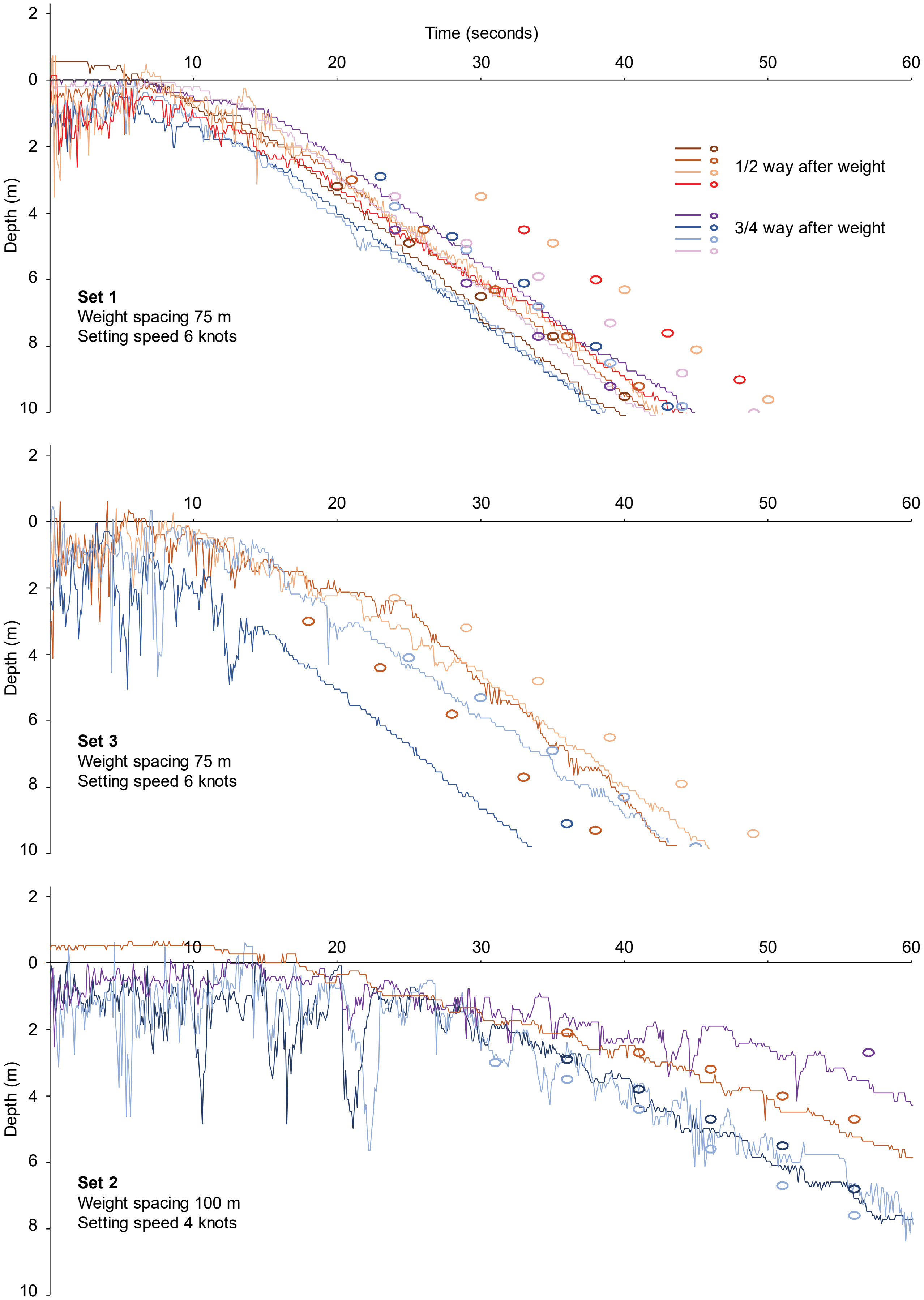


Figure 10. Plots of CEFAS TDR and Wet Tag data by set. Lines represent CEFAS TDR data and open circles Wet Tag data. Colours indicate paired deployments.

Wet Tags produced similar results to CEFAS TDRs for times to 5 m depth, whereas Star Oddi TDRs recorded consistently longer times (Table 5)

Table 5. Position on longline and times to 5 m depth recorded by different recorders for sets 1 and 3. Note that deployments were in pairs, and that each line represents a separate dataset, only including data where records were available from both pairs. Standard deviation is shown in round brackets and the number of records in square brackets.

CEFAS						**Wet Tag**					
1/2			3/4			1/2			3/4		
28	(25-30)	[6]	26	(23-28)	[5]	29	(21-36)	[6]	27	(30-24)	[5]

CEFAS									**Star Oddi**								
1/2			3/4			dropper			1/2			3/4			dropper		
28	(25-32)	[8]	27	(23-30)	[8]	12	(8-15)	[6]	33	(37-29)	[8]	32	(38-26)	[8]	19	(23-15)	[8]

TDR pressure offsets for up to 50 m for Starr Oddi TDRs and 11 m for CEFAS TDRs were applied. Star Oddi temperature correction post-hoc using substituted temperature values resulted in slightly deeper depth records (Figure 11)

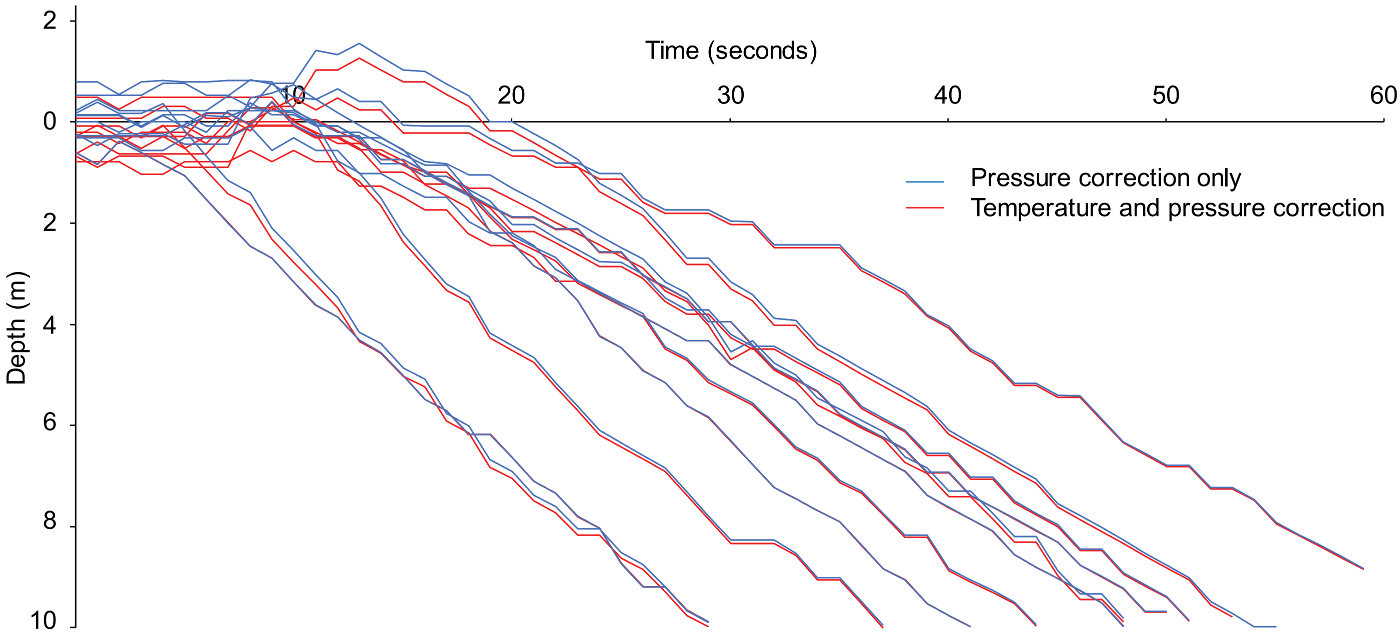


Figure 11. Time vs depth plots for Star Oddi TDRs deployed on set three, with and without temperature correction applied.

Bottle tests

Bottles tests were slightly more difficult to deploy than TDRs as it was necessary to ensure there was minimal slack in the rope to avoid tangles. After deployment the reflective tape was initially easily seen with a handheld spotlight. However, once some distance astern, swell waves and vessel movement resulted in the bottle being 'lost' behind waves. Consequently, the times recorded should be considered as 'last time bottle was visible'. Bottle tests consistently underestimated sink times to five metres, when compared to CEFAS TDRs (Table 6).

Table 6. Time taken for the backbone to reach five metres, as measured by bottle tests and CEFAS TDRs for paired deployments.

Line	1	1	1	1	3	3	3	3	**mean**	**(+/- sd)**
CEFAS TDR Time to 5m (s)	24	27	26	29	35	33	33	35	30	(26-35)
Bottle time to 5 m (s)	18	24	19	22	28	21	32	25	24	(19-28)

Controlled drops

When deployed together in controlled drops there was variation in accuracy between individual TDRs with reasonably random errors compared to measured depths. One Star Oddi TDR showed a time offset, and all Wet Tags recorded shallower depths than TDRs (Figure 12)

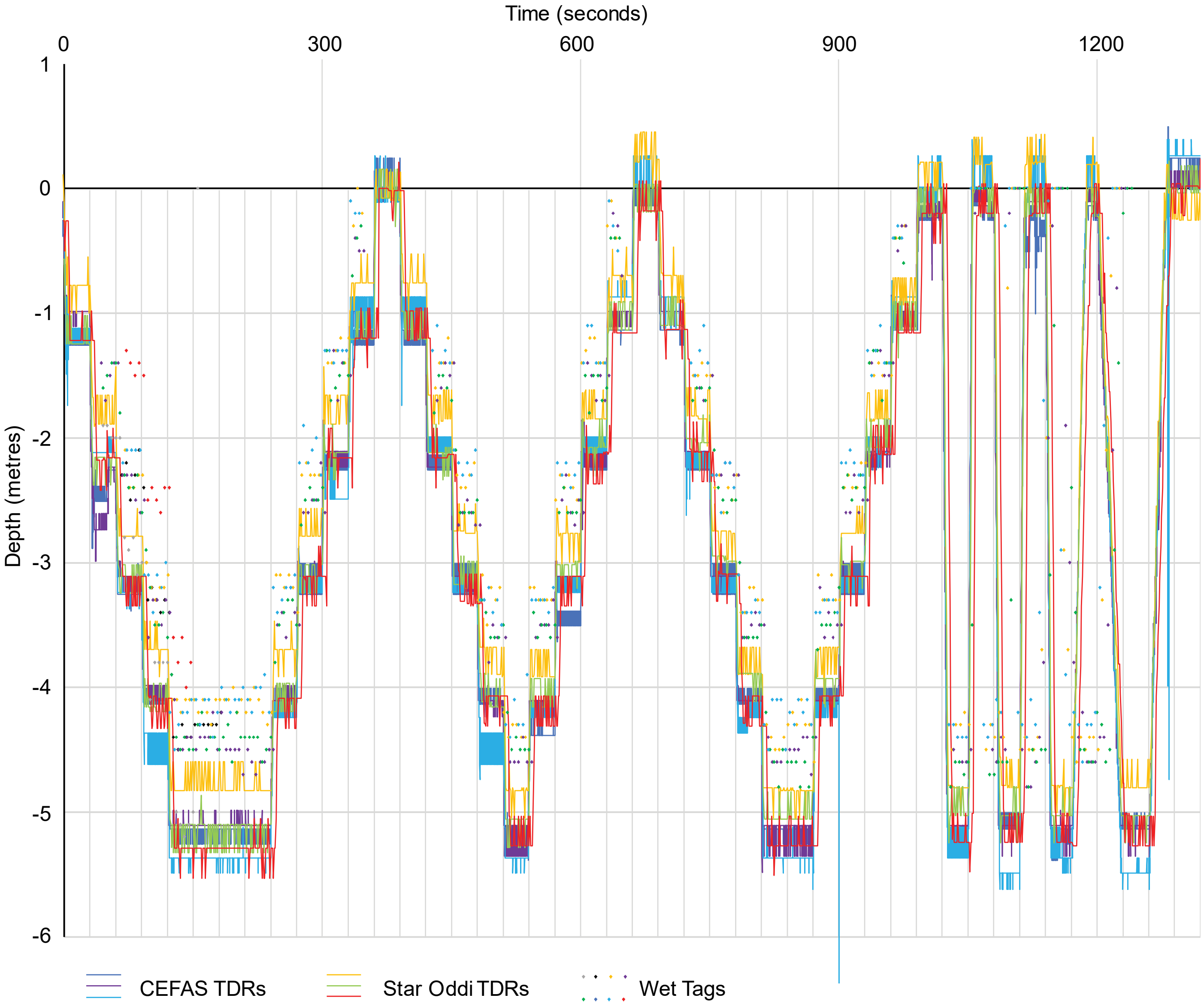


Figure 12. Plot of time vs depth for three CEFAS TDRs, three Star Oddi TDRs and eight Wet Tags deployed together in a series of controlled drops.

Discussion

Pelagic longlines

Surface longline vessels typically set at around seven knots, and are required to use a 75 m long tori line. At this speed tori line coverage of baited hooks lasts for approximately 21 seconds. During this time 13 m long snoods will sink largely independently of the backbone, providing they are clipped onto the backbone within a second or two of casting the baited hook.

Based on the static tests described here, with high r-squared values for regression calculations, initial sink rates are linear, certainly in the first 15 seconds, allowing for calculation of a sink rate rather than a profile or depth at time after deployment. This approach avoids inaccuracies associated with imperfect synchronisation of clocks, pressure offsets, recording of water entry time, and drift on TDR clocks.

Due to starting recording at depth and a five second measurement interval Wet Tags are generally limited to using the first two or three data points to estimate initial sink rate (Figure 6), and typically only one point was collected under the tori line under fishing conditions (Figure 4). Under controlled conditions this appears to provide some relative, but not absolute, measure of the sink profile of different snood configurations. However, when deployed under fishing conditions, much more variation is present (Figures 3-5).

Bait size, species, and thaw status, snood length, delays clipping on, swell, wake, propellor wash, snood length etc. all add variation to real world sink rates. With two plus metre swells regularly encountered it is unlikely that Wet Tags would be suitable for differentiating sink rates between sets without placement on a large proportion of snoods (Figures 2 and 4). However, assuming random errors and data collection over a season with consistent snood set up, some comparison between vessels may be possible.

The results presented here should be considered with respect to the following limitations:

There is some weak evidence that adding a Wet Tag removes some of the variability associated with smaller and lighter CEFAS TDR only deployments (Figure 6).

TDRs were placed at 0.5m from the hook, and all had some weight and bulk, so do not provide a perfect measure of hook sink rate.

The second set of free fall tests were conducted in fresh water, so would be expected to produce faster sink rates than in seawater, and TDRs would be expected to record shallower depths. No corrections have been applied to account for these factors.

The standard deviation presented in the Tables 1 and 2 does not account for error in linear regression calculations, however r-squared values were high, generally greater than 0.99.

Demersal longlines

The introduction of mitigation standards based on longline depth at the end of the tori line is commendable as it allows fishers maximum flexibility in their approach to line setup. A combination of increased line weighting, longer tori lines and slower setting speeds is likely to result. However, this approach requires accurate measurement of sinking lines. Although only a time to five metres is required the sink profiles provided by TDRs provide additional useful information for fishers trying to increase sink rates.

Demersal longlines are typically set at three to six knots, and at higher speeds a longer tori line is desirable, and easier to achieve as a greater drag force is created. Although regulations state a 50 m aerial extent, many vessels will exceed this. In this instance the vessel estimated a 90 m aerial extent, when setting at 6 knots, which gives approximately 29 seconds of protection for lines one and two. Line three would have protection for approximately 44 seconds, assuming the aerial extent of the tori line was maintained at the lower speed. Tori lines with a 50 m aerial extent will provide protection for 16 or 24 seconds at 6 and 4 knots respectively.

Noisy CEFAS TDR sink profiles when deployed with Wet Tags (Figure 10) are likely due to the use of CEFAS housings, rather than Star Oddi ones, as smooth profiles were produced during the free fall tests, without housings.

There is considerable variation in both CEFAS and Star Oddi TDR records between different deployments, even at the same position relative to weights and floats (Figures 8 and 9). Some of this is likely due to measurement errors including TDR clock drift, pressure offset drift and sensor inaccuracies (Figure 12). Using TDRs (and Wet Tags) to measure line sink rates is essentially outside the scope of their quoted accuracy. However, the resolution is adequate, sink profiles make sense and are consistent, so it seems fair to assume that errors are reasonably random and that average sink profiles across several measurements are unbiased and representative. The exception to this is the time offset observed for the Star Oddi TDRs which appear to have a variable clock drift. This was not repeatable for all TDRs over short times between programming and deployment for the controlled drops, but it was detected on one combination.

The offsets in time between CEFAS and Star Oddi TDRs warrant further investigation. Given that both TDR types were programmed and downloaded from the same PC at the same time this disparity is hard to explain. Onboard processing of data in the CEFAS tags may preclude firm conclusions.

Wet Tags had a variable time after immersion and depth at which data collection started, resulting in few, if any, measurements under the tori line. They were unable to distinguish initially slow longline sink rates close to the surface. Both of these limitations cast doubt on their ability to provide useful data to assess risk to birds. If an accurate clip-on time could be collected then data such as that presented in Table 5 could be useful for verification of Mitigation Standards. NFC tags may provide a mechanism for this, but would require a third person (probably the skipper) to scan them. Accurate estimation of consistent delays between scanning and clipping on would also be necessary, but not always easily achieved.

Despite returning to zero depths during the free fall tests Wet Tags tended to under-measure depth, particularly on faster-sinking lines, so may well benefit from a tag-specific depth offset (Figure 12). As Wet Tags do not record at the surface it is harder to apply pressure offsets, especially on a per deployment basis, but this should be considered as it may improve accuracy and agreement between Wet Tag and TDR depths.

The duration of initially slow sink rates recorded on demersal longlines will vary with weight spacing. It appears that once any position on the line has a weight either side of it, and the weights are sinking away from the surface, then the line will sink in a reasonably linear fashion. For gear setups with larger weight spacing (Figure 10) this will take longer.

Errors in bottle test data are biased towards shorter times. Assuming the bottle is successfully clipped onto the longline, the rope is measured correctly, and times are recorded accurately it is not possible to see the bottle above the sea surface if the line is below a depth equal to the length of the rope. It is possible, however, to lose sight of the bottle before it is pulled under, as happened during the tests presented here. Further investigation into the use of bottle tests is recommended, especially if they are to be used for verification of meeting minimum standards. Daytime sets in good weather conditions may provide more reliable and repeatable results.

Whether pulling the bottle underwater slows sink rates should also be considered, but if it could be seen clearly then noting the time at which it stood upright immediately prior to sinking would alleviate this potential problem.

Higher resolution and faster sampling tags, such as the 'Moana' device, are available from Zebra Tech and due to be employed routinely on demersal longlines. If a clip-on time can be collected, for example using time stamped EM footage and/or NFC tags, and data can be collected shortly after immersion, then these may provide for regular monitoring of sink rates.

Plots have been presented in time after recorders were clipped onto the longline. Converting this to a distance astern requires measurement of speed which may vary on a set-by-set basis. In this case line two was set slower in order to clip hooks on at shorter spacing.

Conclusion

Pelagic longlining

Mitigating seabird bycatch using line weighting in the surface line fishery relies on hooks initially sinking independently to the backbone, with sink rates increased by adding weight into the snood, close to the hook. Therefore, to assess the availability of hooks to seabirds it is necessary to add recorders onto snoods, as close as possible to the hook. To minimise influence on sink rate recorders should be as small as possible and have a density close to that of seawater.

Wet tags are not particularly suitable for assessing initial pelagic longline hook sink rates on a set-by-set basis, due to the delay in switching on and five second sample rate. However, data collected by Wet Tags is likely to be of interest to fishers, particularly regarding fishing depth and temperature profiles. Wet Tags may also be useful in assessing the frequency with which hooks are brought close to the surface and available to birds during the soak.

As the pelagic longline Mitigation Standards are input based, there is no need to verify hook depth at the end of the tori line on a regular basis. This is a reasonable approach, given that there is a large body of literature around the efficacy of different line weighting options in this fishery, and that hook shielding devices operate to a fixed depth.

More generally, this work highlights that there is considerably more variation in real world conditions, compared to controlled conditions. It is important to consider this variation when assessing risk and, as birds are able to actively search behind the vessel or tori line, the slower end of this variation is most important.

Introduction of a minimum snood length to the mitigation standards is recommended, to ensure that hooks are sinking at maximum rates, independently of the backbone, at least under the tori line.

Demersal longlining

Wet Tags were not able to identify initially slow sink profiles close to the surface and took few measurements before hooks passed beyond the tori line aerial extent. Without a zero or 'clip-on' time Wet Tag data cannot directly measure the depth of longlines at distances behind the vessel. However, if this start time can be recorded, for example using NFC tags or EM video footage, Wet Tag data will be useful.

Using fisher-collected data for estimating risk and/or verification for meeting mitigation standards would require measurement of tori line aerial extent, setting speed, gear setup including weight and float sizes employed along the line, and the position on the line in which recorders were attached. Given this is unlikely to all be achievable through EM, it may be easiest to have an independent observer, liaison officer, or technician go onboard the vessel and collect TDR data.

Bottle test comparisons with TDR data should be conducted under favourable conditions to assess whether better visibility, and potentially a higher observation point, produces more comparable results. Due to one-sided errors bottle test results should be considered optimistic, especially in less-than-ideal conditions, and if several repeats are conducted selecting the slowest times seems appropriate.

Overall Conclusions

The time offset between CEFAS and Star Oddi TDRs and Wet Tags warrants further investigation, as does application of pressure offsets to Wet Tag data.

The usefulness of per set post-hoc sink rate data for skippers should be considered before investing further resources. Assuming consistent gear setup, between set variation is small relative to within set variation (This study, Goad et al., 2010, Goad 2011, Pierre et al. 2013, 2015). Therefore, skippers can be provided with average sink rates achieved by different gear configurations with data collection from one or two sets, and these should be useful in selecting gear set up prior to setting. Given that the main remaining variable driving setting mitigation success is likely to be bird abundance and behaviour, then bycatch numbers provide the only true post-hoc measure of success.

Irrespective of depths of the backbone at the end of the tori line, effective mitigation will still require vigilant and conscientious crew and skippers. Given that, even paired, tori lines are not always effective and some birds can comfortably operate at considerable depths, there will continue to be times and places when fishers must either operate beyond the mitigation standards, and / or stop fishing to minimise their chances of catching birds.

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