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Propeller turbulence and its effect on the sink rate of baited hooks in pelagic longline fisheries

Australia

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PROPELLER TURBULENCE AND ITS EFFECT ON THE SINK RATE OF BAITED HOOKS IN PELAGIC LONGLINE FISHERIES

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Abstract

Thrust from the propeller of pelagic longline vessels has the potential to slow the sink rates of baited hooks and increase the risk of fatal interactions with seabirds. Experiments were conducted on fishing vessels to determine the effect of turbulence on the sink rates of baited hooks. Five bait landing positions were assessed: directly over the centre line of the turbulence, into the wake on both upswing and downswing sides of the propeller, and outboard of the wake positions on either side of the vessel. Two branch line deployment methods were assessed: dragging leaded swivels in the turbulence before deploying baits to assigned landing positions (the sivel first method), and deploying hook and swivel together to assigned positions (the hook-and-swivel together method. Except for the centre position, the within-vessel differences in bait landing position were small. Thrust in the wake zone on both upswing and downswing sides of the propeller, and in the clear water areas on either sides of the vessel, did not markedly affect sink rates. Sink rates in the centre position were markedly slower than rates in the other four positions for both vessels and with both branch line throwing methods. There were no differences between branch line throwing methods for all positions except the port wake, in which the swivel first method yielded the fastest rates. Gear set to the port wake (upswing side of propeller) and starboard far positions yielded the fastest, or among the fastest, sink rates in the 0-3 m range. Of these two positions the port wake position is the prefered option. Baits set into this position may be disguised by aerated water from the propeller and the bird scaring streamer line is more easily rigged in this area of vessels.

Keywords: Seabird by-catch; Pelagic longlines; Propeller turbulence; Baited hooks; Sink rates

1. Introduction

Following recent reductions in seabird mortality in demersal longline fisheries operating in the Southern Ocean (Croxall et al., 2007; SC-CCAMLR 2008) attention has turned to fisheries operating in tropical and sub tropical waters. Fisheries in these regions include pelagic longline fisheries for tunas (*Thunnus* sp) and swordfish (*Xiphias gladius*), which continue to take large numbers of migratory seabirds (Bugoni et al., 2008; Petersen, 2008; Jiménez et al., 2009). One of the most effective means to avoid seabird mortality in demersal longline fisheries is to increase the sink rate of longlines (Agnew et al., 2000; Robertson et al., 2006; Moreno et al., 2008). This is also likely to be the case in pelagic longline fisheries. However, efforts to expedite the sink rate of pelagic branch lines are complicated by gear design (e.g., Robertson et al., submitted), setting practices (e.g., Robertson et al., in press) and the effect of propeller turbulence on sinking hooks. Gear is usually deployed off the stern of tuna and swordfish vessels either into or beside turbulent water from the propeller, or outboard of vessel wake. A study in the Australian tuna fishery showed that baited hooks attached by branch lines to mainline set into propeller turbulence sank significantly slower than hooks attached to mainline set so as to avoid turbulence (Robertson, et al. in press). Water swirling from the propeller around the mainline causing the mainline to loft is the only plausible explanation for this finding. The same may occur if baited hooks are deployed into or near propeller turbulence. Pelagic branch lines vary in length from 15-40 m (c.f. < 1 m in demersal) and are set by hand or with the aid of a bait casting machine (Lokkeborg, 2008), and often off both sides of vessels. Thus, pelagic crews have a range of options regarding bait landing positions and proximity to the propeller not available to demersal longline crews because of the short snood lengths. Crews also have options regarding methods of throwing branch lines which may influence how they land in the water and interact with propeller turbulence. Having a range of bait placement positions and branch line deployment methods may have important implications for the sink rate of baited hooks and their availability to seabirds.

Here we describe the results of experiments to test the hypothesis of no difference in sink rates between baited hooks deployed in various positions in relation to propeller turbulence, and by different branch line throwing methods. The bait landing positions were i) directly over the propeller (centre position) ~1 m from the stern, ii) edge of vessel wake on the upswing side of the propeller, iii) edge of vessel wake on the downswing side, iv) clear water on the upswing side, and v) clear water on the downswing side. Deployment in the centreline position is typically used in the Uruguayan swordfish fishery, ostensibly to reduce interactions with seabirds (S. Jiménez, personal observations). In Chile, Brazil, South Africa, New Zealand and Australia baited hooks are most commonly deployed into the edge of vessel wake on one or both sides of vessels. In the Japanese distant water tuna fishery baited hooks are deployed into the outer area of the wake if thrown by hand (G. Robertson, personal observations), or beyond the wake into water not visibly affected by turbulence if set with a bait casting machine (deduced from Melvin, et al., 2009). The bait throwing methods were the swivel first method and the hook-and-swivel together method (see below). The bait landing positions and throwing methods examined in the experiment exhaust all known branch line deployment methods used in tuna and swordfish longline fisheries in the southern hemisphere.

2. Methods

2.1 Bait landing positions and bait throwing methods

The two bait landing positions on the edge of vessel wake were defined as being 1 m astern of the point where the stern and side of the vessel joined. The two clear water positions were 1 m astern and 3-4 m outboard of the vessel wake into water not visibly affected by turbulence. The centre position was 1 m astern and directly in the centre line of the vessel (Figure 1). Regarding the branch line casting methods, the swivel first method involved throwing the swivel into the sea and allowing it to drag behind the vessel while retaining the clip and baited hook ends of the branch line. On cue from the audio beep the baited hooks are then deployed to the assigned landing positions. The swivel-and-hook together method involves throwing the baited hook and leaded swivel together in one action so both land in the assigned positions in relatively close proximity to one another. The essential difference between methods is that regardless of bait landing position the swivel first method always involves dragging the swivel in the propeller turbulence behind the vessel. The first method is commonly used in Chile, Brazil, Uruguay, South Africa, New Zealand and Australia. In Australia ~ 80 % of branch lines are deployed by this method and the remainder by the second method (source: Australian Fisheries Management Authority). Branch lines in the Japanese distant water fishery are deployed by the second method.

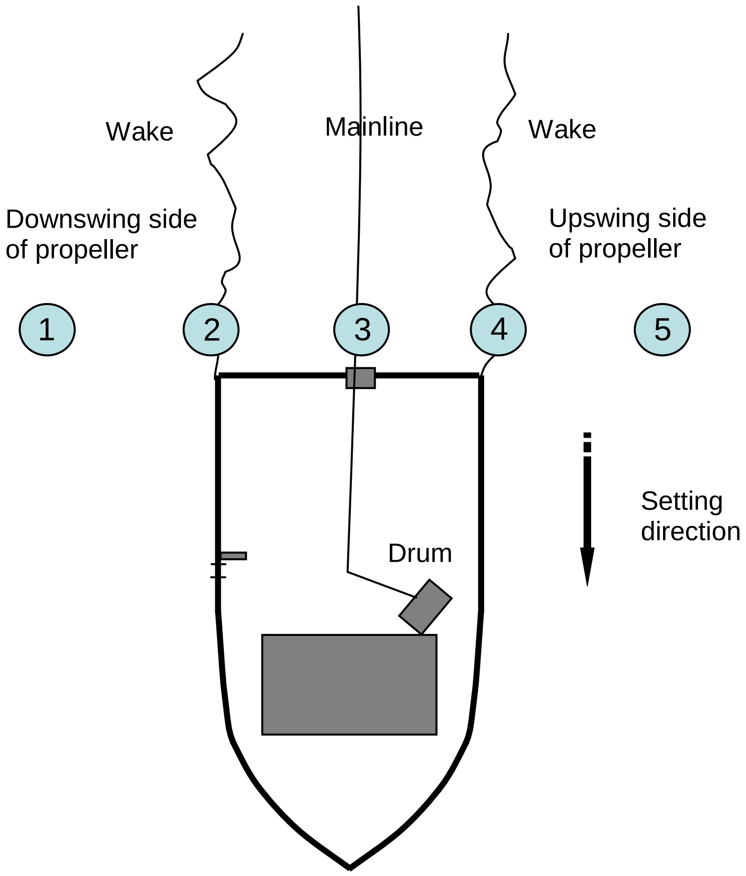

Figure 1. Schematic presentation of the five bait landing positions in proximity to the propeller turbulence assessed in the experiment. In the text the positions are referred to as 1) starboard far; 2) starboard wake; 3) centre; 4) port wake; and 5) port far.

2.2. Experimental design

The experiment was completed in two parts, the first in Chile and the second in Australia. The experiment in Chile examined the five bait landing positions (branch line throwing method was constant) and the experiment in Australia assessed the effect of the two bait casting methods. Both experiments were randomised block designs with each block comprising the five bait landing positions and one deployment method as described above. However, in the Australian experiment the first set of the line adopted the same bait throwing method as in Chile to examine the effect of "vessel", if one existed. A vessel effect could mean some aspects of vessel design or operation, weather or sea condition, were confounded the comparisons. A statistically significant vessel effect would mean the data could not be combined into the one experiment of five landing positions and two throwing methods.

In Chile the longline was set and hauled five times, with the first set being a practice run to streamline the operation and to be sure the crew could consistently throw baited hooks to the assigned positions. Since there were five landing positions and 25 time-depth recorders (TDRs, see below) available for deployment on each set, each set and haul cycle involved five replicates for each of the five landing positions. Thus, there were a total of 20 replicates for each of the five bait landing positions (ie., four experimental sets x five replicates/set). TDRs were assigned to individual branch lines and the deployment positions randomised within each set to account for any potential biases (known or unknown) due to deployment order or sea conditions, and to safeguard against instrument loss or failure. In Australia the longline was set and hauled four times, with each set involving deployment of 40 TDRs. In the first set, which involved eight replicates for each of the five landing positions, baited hooks were thrown by the same method used in Chile to determine if a vessel effect existed. The remaining three sets were dedicated to the second bait throwing method.

2.3. Fishing vessels and propeller characteristics

The experiment in Chile was conducted on the F/V *Estefanía Carolina*, about 5 km southwest of Coquimbo (29°57′S, 71°20′W) on 20 January 2009. The vessel was chartered especially for the experiment and was not fishing commercially. The *Estefanía Carolina* is an 18 m long steel longliner operating in the Chilean swordfish and tuna fishery. The *Estefanía Carolina* has a displacement hull and a single four blade constant pitch propeller. The propeller was 1.52 m in diameter and rotated in a clockwise direction when facing towards the bow. Gear was set from the stern (6.5 m wide) at a constant 8 knots (1,600 rpm). The drum holding the mainline was run at a speed (in relation to the forward speed of the vessel) such that the mainline entered the water 25-30 m astern with a slight downward sag, which is the typical configuration for the fishery. The mainline left the vessel through a guide ring at the centre of the stern 2.81 m above sea level. The vessel set into the swell, which was a gentle roll to 1 m. There was virtually no wind.

In Australia the experiment was conducted on the *Sarah-J*, about 20 km east of Mooloolaba (26.41' S; 153.07' E) on 19 January 2010. The *Sarah-J* was chosen because of its similarity to the *Estefania Carolina*. The Sarah-J is a 22 m long, 6.2 m wide, steel longliner working the Australian tuna and swordfish fishery. The vessel has a displacement hull and a four blade constant pitch 1.45 m diameter propeller. As with the *Estefania Carolina* the propeller on the *Sarah-J* rotated in a clockwise direction when facing the bow. Setting speed was identical to that for the *Estefania Carolina* (8 knots; 1,500 rpm) and the mainline left the vessel through a line shooter 2.6 m above sea level and entered the water 25-30 m astern. The vessel set with the tide (~ 0.3 knots) and swell, which was a gentle roll to 1 m.

2.4. Fishing gear

The *Estefanía Carolina* used monofilament mainline (3.5 mm diameter) and branch lines (2.1 mm) typical of the American system of longlining described by Vega and Licandeo (in press), except that branch lines did not contain a length of wire near the hook. All branch lines used in the experiment were build by ship’s crew to specifications from new monofilament line. TDR branch lines and non-TDR branch lines were stored in separate bins. The 25 branch lines holding TDRs (see below) were 20 m in total length and the mean distance between leaded swivels and hooks was 2.80 m (range: 2.80-3.30). Swivels were nominally 75 g, which are required in the fishery, but in reality included some of 60 g (see Discussion). Bait used was whole mackerel (*Scomber japonicus*) with a mean length and mass of 30.01 cm (range: 28.5-32.8 cm; n = 30) and 326.0 g (range: 275-365 g), respectively. Hooks were # 18/0 J-type (17.5 g) and were attached through the muscle 5 cm from the tail. All bait was in an approximately half thawed state when deployed.

The *Sarah-J* also used 3.5 mm mainline and for the experiment was equipped with 2.0 mm monofilament branch lines (0.1 mm smaller in diameter than that on the *Estefania Carolina*). All branch lines deployed in the experiment were purpose built from new materials. Branch lines measured 17 m from clip to swivel and 3.0 m from swivel to hook. Leaded swivels weighted 60 g and hooks were identical to those in Chile. Hooks and bait hooking position were the same as on the

Estefania. Bait was whole blue mackerel (*S. australasicus*) with a mean length and mass of 26.9 ± 1.1 cm (range: 24.5-29.0 cm; n = 20) and 251.2 ± 25.6 g (range: 190-300 g), respectively.

2.5. Sink rates

Sink rates on both vessels were measured using DC centi TDRs (Star Oddi company, Iceland). On the *Estefania Carolina* the devices were configured to record depth at 0.07 m intervals every second through a 1-280 m recording range. The TDRs were refurbished by the manufacturer prior to the experiment on the *Sarah-J* to record at 0.03 m intervals through a 1-100 m range. They measured 15 mm x 46 mm, weighed 19 g in air when used in Chile and 21.0 g following refurbishment. Prior to both experiments the TDRs were sunk to 2 m depth (1 m deeper than the start of instrument recording range) for five minutes to determine the offset. The source of the offset is the difference between the temperature of the instruments and the temperature of the seawater when deployed (source: Star Oddi company). The value 10 seconds after reaching 2 m depth was taken as the calibration offset value because by then the depth readings had stabilized (the temperature of the sea and the air differed by < 1 degree C). The TDRs were attached to branch lines 30 cm from hooks following Robertson, et al. (in press) and were assumed not to have affected the sink rates of baited hooks (Robertson et al. in press.). The TDRs were synchronised with internet (atomic) time via a computer and a digital wrist watch, which was used to record the exact water entry time (nearest second) of each deployment. Before deployment on the *Sarah-J* the TDRs were immersed in a 100 L drum of seawater for 90 seconds before deployment to ensure the TDRs and seawater were the same temperature. On completion of the experiments data was downloaded to computer and each sink profile 'corrected' according to the calibrated 2 m offset values.

2.6. Setting procedure

The setting procedure was the same on both vessels. A radio beacon and float (40 cm diameter) were deployed first to 'anchor' the start of the line. Mainline with no branch lines attached was then payed out for two sections of six beeps on the timed audio system. This equated to 168 seconds or 689 m of mainline, based on there being 14 seconds/beep and 4.1 m/s setting speed. On each of these two sections of six beeps a float (45 x 20 cm on the *Estefania* and 0.45 m diameter on the *Sarah-J*) was deployed on a 15-18 m downline. On completion of this initial section of mainline branch lines were deployed in a series of float sets as in normal fishing operations. Each float set comprised five branch lines flanked by a float on a downline as mentioned above. TDRs were attached to the third branch line (centre position) in each float set. Thus each float set of five branch lines comprised one TDR branch line and four non-TDR branch lines. Branch lines were attached to the mainline at 14 second intervals, making them 57 m apart (14 seconds x 4.1 m/s setting speed). By this configuration TDR branch lines lay 342 m apart.

Float sets were deployed continuously (no gaps between them) until all TDR branch lines had been deployed. When all branch lines in a set were deployed another 689 m (12 beeps) of mainline was deployed without branch lines attached to allow enough time for the last branch line to sink to sufficient depth. The gear was then hauled onboard and the procedure repeated.

The TDR branch lines were deployed according to the randomised position required by the experimental design. On both the *Estefania* and *Sarah-J* non-TDR branch lines were deployed systemmatically on both sides of the vessel at the edge of the ships wake (positions 2 and 4, Figure 1), which was the normal procedure with crew fishing operations. This decision was taken to simplify procedures for the crew so they could concentrate on the randomized order of assigned bait landing positions with the TDR branch lines. Since branch lines were 57 m (14 seconds) apart it was assumed the sink rate of TDR branch lines was not affected by that of the preceeding branch lines. This is a reasonable assumption, because at 57 m apart non-TDR (and TDR) branch lines were well beyond the area of water affected by the propeller before subsequent branch lines were deployed. Landing gear in the starboard far and port far positions with the swivel first throwing method (the swivel was always set into propeller wash before the bait was thrown) was possible because baited hooks were 3-5 times heavier than the swivels.

On the *Estefania Carolina* all branch lines (TDR and non-TDR) were thrown using the swivel first method only. As mentioned above, the first set of 40 TDR branch lines were set from the *Sarah-J* using the swivel first method to determine if sink characteristics differed between vessels. This gave eight replicates for each of the five landing positions for the purposes of the vessel comparison. The remaining three sets were dedicated to the second throwing method, which gave a potential 24 replicates for each of the five landing positions.

2.7. Data analysis

2.7.1. *Main depth ranges*

In previous sink rate studies we confined comparisons to the 0-5 m (Robertson et al., in press) and 0-6 m (Robertson et al., submitted) depths in the water column because this is where baits are most assessible to seabirds. While the analysis in the current study addresses effects in the 0-6 m depths of the water column, the main depth of interest is the 0-3 m range because this is the depth range most affected by the propeller. The bottom of the propeller on the *Sarah-J* lay 2.7 m below the water line of the vessel. (see below). Propeller thrust mainly flows in an upwards and inward direction and there is very little dispersal below the lower extremity of the propeller (Lewis, 1988). Hence, the 0-3 m range is the main focus of the study.

2.7.2. Analysis

Since the swivel first method was only used in the trial carried out on the *Estefania Carolina* two separate analyses were carried out. The first used the sink profiles for only the swivel first method for the *Sarah-J* trial and combined these were the profiles for the *Estefania Carolina*. This analysis considered the two factors and the interaction of Vessel and Landing Position as the fixed effects. The second analysis was restricted to the Sarah-J trial data and considered the two factors and the interaction of throwing method and landing position. Depths to times of 1 to 30 seconds were analysed in each case using the methods described in Robertson et al. (2010) using linear mixed models incorporating cubic smoothing splines.

The graphical comparison of average sink profiles given in the results employs confidence bounds placed at the bottom of each graph for clarity. If differences between average profiles for a given time are greater than the bounds then the difference can be considered significant at the 95% level. Since these confidence bounds are determined by multiplying the standard error of the predicted mean depth at a given time on the log scale by the predicted mean depth, the bounds will depend on which set of predicted mean depths have been used therefore the bounds for each level of the factor are shown when there are more than two profiles overlaid. Comparison between pairs of factor levels should use the average of the bounds relevant to the comparison. For graphs showing only two profiles this averaging has been carried out (to give a single confidence bound in each panel) taking into account the different number of profiles used to obtain the average profile in each case.

3. Results

Of the potential 20 replicates for each of the five landing positions on the *Estefania Carolina* 11-14 TDR profiles per position were available for analysis with a total of 71 profiles retained for analysis. The remainder were omitted due to instrument failure or innacuracies in recording the exact time of water entry. Of the potential 8 replicates per position set (= 40 sink profiles) from the *Sarah-J* with the swivel first throwing method 39 were available for analysis. Of the potential 24 replicates per position for the hook-and-swivel together method on the *Sarah-J* 22-24 per position were available for analysis with a total of 112 profiles retained for analysis. One TDR failed to collect data, one profile was omitted because the bait fell off in the throw and another was omitted because the water entry time was not accurately recorded. The data for three additional profiles were removed because for two of these the depth stayed under 1 meter for the entire 0-30 seconds range while the remaining depth profile showed that the branch line had been dragged upwards after 20 seconds.

3.1. Sink profiles

3.1.1. Vessel effect

The sink profiles of gear in all five landing positions using the swivel first throwing method (common to both vessels) were sigificantly different between vessels ($P < 0.01$); Figure 2). Thus, the results from both experiments cannot be combined. Gear set from the *Estefania Carolina* sank faster in all five landing positions than gear from the *Sarah-J* and the order of the profiles differed between vessels. With respect to the *Estefania Carolina*, differences between some of the profiles were statistically significant. However, overall the differences were minor. The main finding for this vessel was that baits set to the centre position were 2.0-3.5 m shallower after 30 seconds than hooks set to the four other positions. Profiles from the *Sarah-J* are assessed below.

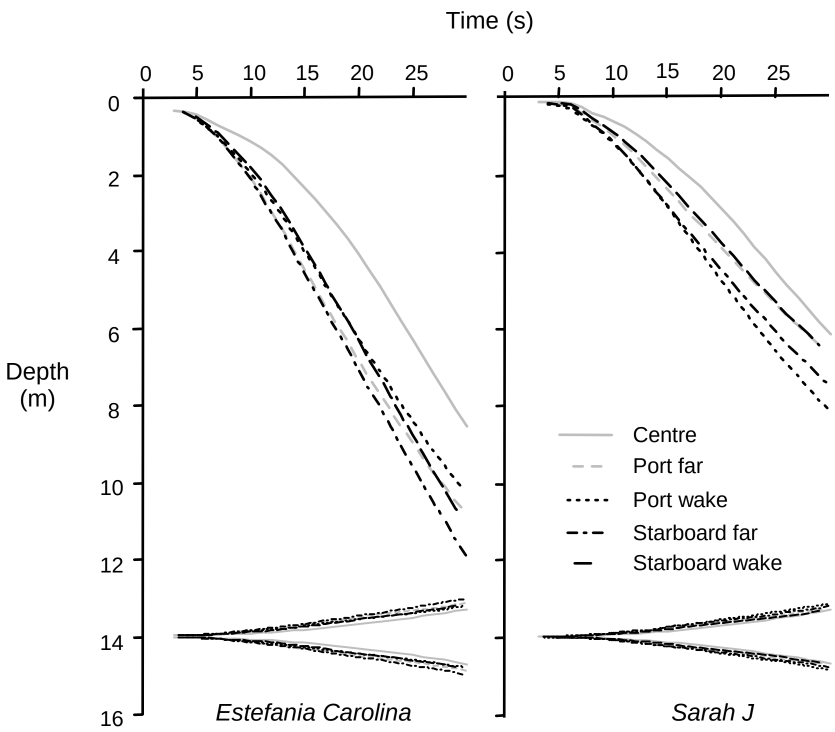

Figure 2. Comparison of sink profiles of baited hooks set from the F/Vs Estefania Carolina *and* Sarah-J *in the five bait landing positions related to propeller turbulence. The comparison is based on the swivel first branch line deployment method, which was the method common to both vessels.*

3.1.2. Bait landing position within throwing method

Comparison of the two bait throwing methods is possible only for the *Sarah-J* because baits set from the *Estefania Carolina* with the swivel first method only. The sink profiles with the hook-and-swivel together method were very similar, with baits in all five positions being spaced by < 0.5 m vertical distance after 30 seconds (Figure 3). The effect of propeller turbulence with this method of deploying branch lines was virtually non existent. In contrast, sink profiles of branch lines with the swivel first method varied depending on where they landed. Baits set to the centre, port far and starboard wake positions lay within ~0.5 m of each other after 30 seconds. Baits set to the port wake and starboard far positions were 1.5-2.0 m deeper than those set to the other three positions after 30 seconds.

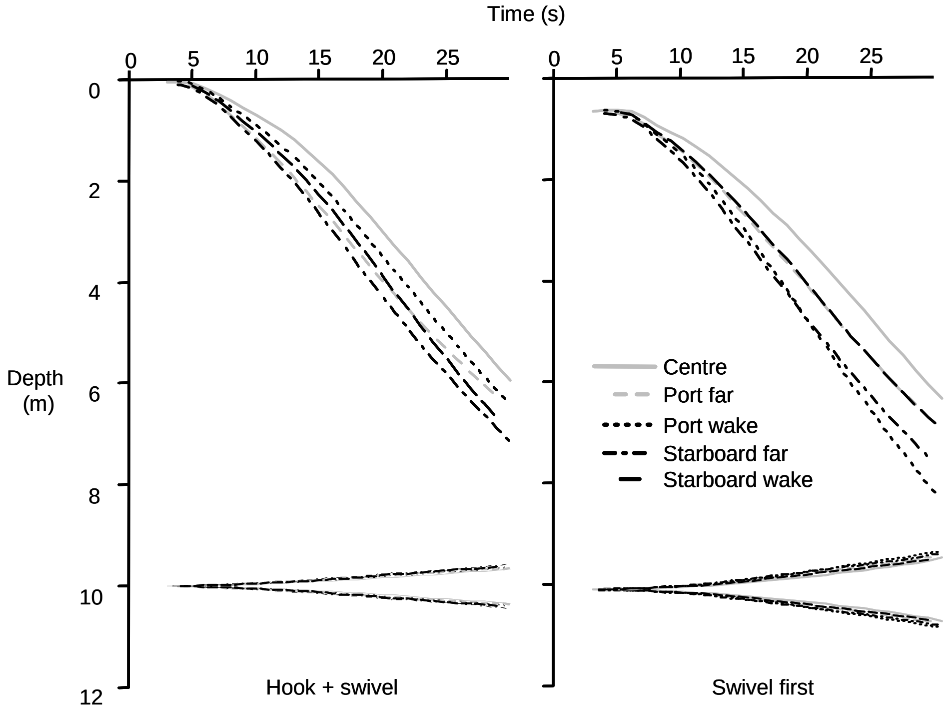

Figure 3. Comparison of bait landing positions within branch line throwing method in relation to turbulence from the propeller of the Sarah-J. *The profiles for the swivel first method are identical to those for the Sarah-J in Figure 2, but appear slightly different because of the different scales on the depth axis of both graphs.*

3.1.3. Throwing methods within bait landing positions

Figure 4 shows profiles for bait throwing method within the five landing positions. The presentation accentuates the fact that within the centre, port far and starboard wake positions the method of branch line deployment made no difference to the sink profiles. Within both port wake and starboard far positions, deploying gear with the swivel first method resulted in significantly ($P < 0.01$) deeper depths attained after 30 seconds compared to the hook-and-swivel together method.

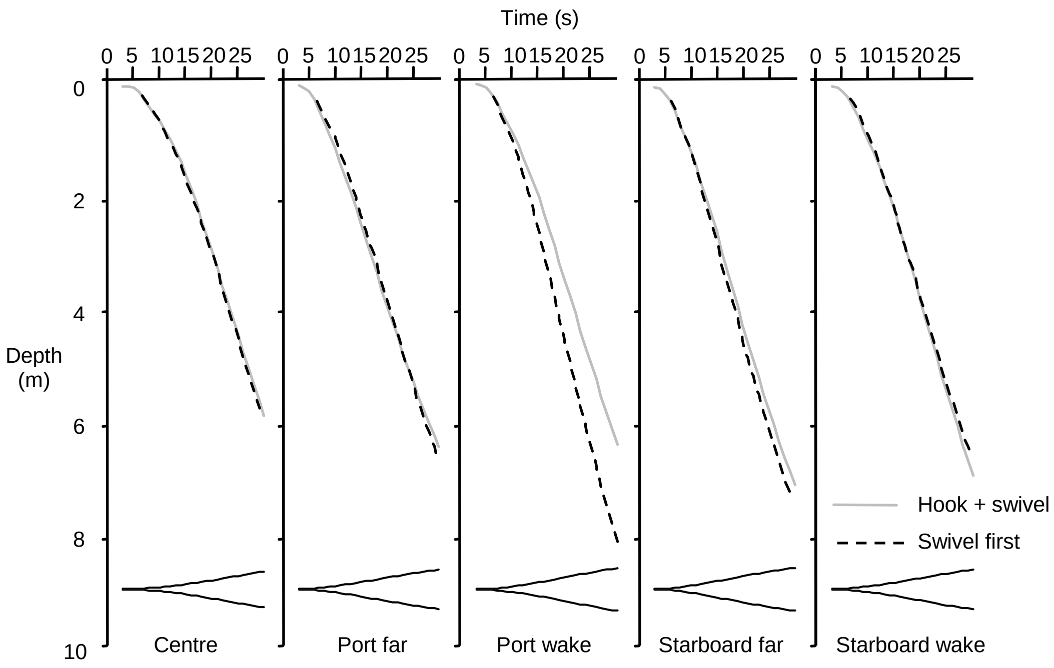

Figure 4. Comparison of bait throwing method within the five bait landing positions in relation to thrust from the propeller of the F/V Sarah-J.

3.2. Sink rates

The mean sink times and mean sink rates are shown in Table 1. In the 0-3 m range baited hooks set from the *Estefania* with the swivel first method reached 3 m depth in similar times for all landing positions except the centre position. Baits set in the centre were, on average, ~5 seconds slower clearing surface waters. Sink times on the *Sarah-J* with the swivel first method ranged from 15.4 s (0.19 m/s) to 20.0 s (0.15 m/s), with the port wake and starboard far positions the fastest. Comparable data (0-3 m) for the hook-and swivel together method ranged from 16.7 s (port far position; 0.18 m/s) to 19.9 s (centre position; 0.15 m/s).

Vessel name	Throwing method	Landing position	Mean sink time (s)		Mean sink rate (m/s)	
			0-3 m	0-6 m	0-3 m	0-6 m
Estefania	SF	S. Far	11.9	17.9	0.25	0.34
Estefania	SF	S. Wake	13.2	19.5	0.23	0.31
Estefania	SF	Centre	17.4	24.4	0.17	0.24
Estefania	SF	P. Wake	12.8	19.5	0.24	0.31
Estefania	SF	P. Far	11.8	17.9	0.26	0.33
Sarah-J	SF	S. Far	15.4	24.5	0.19	0.24
Sarah-J	SF	S. Wake	17.4	27.2	0.17	0.22
Sarah-J	SF	Centre	19.8	29.8	0.15	0.20
Sarah-J	SF	P. Wake	15.9	23.7	0.19	0.25
Sarah-J	SF	P. Far	17.2	27.3	0.17	0.22
Sarah-J	H+S	S. Far	16.1	25.7	0.18	0.23
Sarah-J	H+S	S. Wake	17.3	26.6	0.17	0.22
Sarah-J	H+S	Centre	22.0	30.0	0.15	0.20
Sarah-J	H+S	P. Wake	18.3	28.5	0.16	0.21
Sarah-J	H+S	P. Far	16.1	25.7	0.18	0.23

*Table 1. Mean sink times and mean sink rates in the 0-6 m and 0-3 m depth ranges as a function of one branch line setting method and bait landing positions (*Estefania Carolina*) and two bait throwing methods and five bait landing positions (*Sarah-J*). Sink times and rates for 0-6 m depth are cumulative, and those for the 0-3 m range address the depth most affected by propeller turbulence (see text). Bait throwing methods*

were the swivel first (SF) method and hook-and-swivel (H+S) method. The bait landing positions were starboard far (S. Far), starboard wake (S. Wake), centre (Centre), port wake (P. Wake) and port far (P. Far).

4. Discussion

4.1. Effect of vessel

The significant effect of "vessel" (and/or environmental conditions) was surprising and unexpected. After 30 seconds the fastest sinking baits from the *Sarah-J* reached the same depth as the slowest sinking baits from the *Estefania Carolina*. The depths attained from the *Estefania Carolina* are consistent with mean sink rates recorded in experiments on two other vessels with the same mainline tension, branch line design, bait casting method and bait landing positions behind the vessels (see Robertson et al., in press, and Robertson et al., submitted). This suggest that the sink rates from the *Estefania* might be considered to be more typical for this style of vessel. Presumbaly there are features of each vessel unrelated to gear design and operational procedures that not only affected the maximum depths attained after 30 seconds but the depths associated with each bait landing position (e.g., differences in propeller design and hull shape). Even so, the main finding with the entire profiles is not the sink rates *per se* but the between-vessel differences in the order of the profiles (see Figure 2). Comparison of sink times and rates to 3 m depth between vessels modifies the picture. The centre position aside, which yielded by far the slowest times for both vessels, the time taken to reach 3 m depth for the four other landing positions of both vessels varied by < 2 seconds. This indicates that the within-vessel differences in the propeller zone to all landing positions (other than the centre position) were relatively small, and that the differences increased (and became more obvious) in the deeper depths.

4.2. Sink profiles: F/V Sarah-J

Thirty seconds after deployment the vertical separation of baited hooks set from the *Sarah-J* with the hook-and-swivel together method into all five positions was < 1 m. We consider this difference to be insignificant. Thus, the rotation direction of the propeller and the landing positions in relation to propeller thrust made practically no difference to sink profiles of baits thrown by this method. In comparison, after 30 seconds baited hooks thrown with the swivel first method to the five positions were separted by ~2 m vertical distance. Hooks set in the centre, port far and starboard wake positions yielded similar profiles and depths after 30 seconds, but baits cast in the port wake and starboard far positions reached 6 m deep about 8 seconds before baits in the other three positions. Since landing position made little difference with the hook-and-swivel together method, and since there were differences associated with the swivel first method, the results for the entire profiles suggest that irrespective of throwing method baited hooks sink fastest if caste into the port wake or starboard far positions.

4.3. Sink times and rates

The LMM analysis treats the data as a continuum throughout the 30 second recorded range. While this permits assessment of the entire profiles and time to maximum depths, the analyis emphasises contrasts near the end of the range because this is where differences become more obvious. As mentioned above the main focus in this study is the effect of propeller thrust which, on the *Sarah-J*, is confined to the upper 3 m of the water column. The sink rate results for the *Estefania* with the swivel first method are essentially the same as the cumulative rates to 6 m deep - that is, sink times/rates to 3 m were similar except the centre position, which reduced sink rates by 0.06-0.09 m/s compared to the rates in the other four positions (Table 1). Baits reached 3 m depth quickest when set in the port wake, starboard wake and starboard far positions. The same throwing method off the *Sarah-J* also resulted in a markedly slower rate in the centre position. Sink rates among the other four positions varied by as little as 0.03 m/s (0.16-0.19 m/s), with the port wake and starboard far positions yielding the fastest rates. The results for the hook-and swivel together method off the *Sarah-J* ranged from 17.0-19.9 seconds, or 0.15-0.17 m/s. As with the overall sink profiles, there was very little difference in sink times and rates to 3 m depth with gear set by the hook-and-swivel method from the *Sarah-J*.

5. Conclusion

The difference between vessels with respect to the entire sink profiles cautions against generalising the findings from one vessel to an entire fleet. That said, it must be noted that for the findings to be practical to fishing operations and relevant to fisheries managers (and observer programs) a certain degree of generalisation is necessary. It is important to focus on key differences between effects, not differences that are relatively minor. The primary findings for the propeller zone (0-3 m) are:

a) except for the centre position, the within-vessel differences in bait landing position were small. Thrust from the propeller in the wake zone on both upswing and downswing sides of the propeller, and in the clear water areas on either sides of the vessel, did not markedly affect sink rates;

b) sink rates in the centre position were markedly slower than rates in the other four positions for both vessels and with both branch line throwing methods;

c) there were no differences between branch line throwing methods (*Sarah-J*) for all positions except the port wake (upswing side of prepeller), in which the swivel first method yielded the fastest rates;

d) based on the results for both vessels and for both branch line throwing methods from the *Sarah-J*, the port wake or starboard far positions are the preferred bait landing positions. Gear set to these positions yielded the fastest, or among the fastest, sink rates in the 0-3 m range.

It is clear from these results that apart from the centre position propeller turbulence has a relatively minor effect on sink rates in surface waters. With respect to the two preferred positions, setting gear to the port wake and starboard far positions has different implications regaring the presence or absence of aerated water from the propeller and the operational effectiveness of the bird scaring streamer line. Aerated water from the propeller may afford some degree of ‘protection’ to seabirds because baits appear more difficult to access in bubbly water than clear water (G. Robertson, personal observations). Water in the port wake position is aerated by the propeller whereas water in the starboard far position is unaffected by the propeller (clear water). Baits sinking in the latter position should be more visible to seabirds. Baits in this position are outboard of the vessel and more difficult to protect with the streamer line, due to the length of the pole required to properly position the streamer line. The advantage of the port wake position is that baits are disguised to some degree by aerated water and more easily protected by the streamer line, due to the ease of is rigging in that area of the vessel. We conclude that if only one bait landing position is adopted in fisheries it should be the port wake position. The port wake lies in the upswing side of the propeller.

6. Advice to management

To maximise sink rates in surface waters baited hooks should not be deployed into propeller turbulence immediately behind vessels. This applies to both methods of deploying branch lines. Deploying branch lines to the other four landing positions does not greatly affect sink rates in the upper reaches of the water column. The prefered landing position is the port wake. This position takes advantage of the potential for aerated water to mask sinking baits and baits in this position behind vessels are easier to protect with a bird scaring streamer line. To maximise sink rates baits should be set in this position and with the swivel first method of deploying branch lines.

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