Risk versus reward: interactions, depredation rates and bycatch mitigation of dolphins in demersal fish trawls

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Risk versus reward: interactions, depredation rates and bycatch mitigation of dolphins in demersal fish trawls

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Running Title: Dolphin interactions in fish trawls
Abstract

An improved understanding of interaction dynamics between dolphins and trawlers is essential for improving bycatch mitigation strategies. *In-situ* observations using video at increasing distances from the net opening during 50 commercial fish trawls, recorded 5,908 common bottlenose dolphin (*Tursiops truncatus*) interactions and provided details on their duration, depredation rates and behaviours. Dolphin interactions with trawls were very common (98% of day-trawls, 118±16 interactions per trawl), with durations and prey consumption positively correlated with the distances ventured into the net. Acoustic deterrents (pingers) had no effect on interaction numbers or durations. Based on *in-situ* observations, the factors that contribute toward dolphin bycatch in demersal fish trawls were likely associated with (1) risky dolphin behaviour (i.e. entering net during hauling, residing deep within trawl for extended periods or social aggression); and/or (2) instability of fishing gear resulting in entrapment. Given the high level of dolphin attendance during most day-trawls, mitigation strategies that focus on improving and monitoring the stability of trawl gear would be more effective than current acoustic deterrent devices aimed at modifying dolphin behaviour.

Keywords: bycatch, common bottlenose dolphin, cetacean, foraging, video observations, fisheries

Introduction

The survival strategy of an organism generally incorporates a trade-off between maximising feeding efficiency while minimising the risk of injury or predation, such that the costs and benefits of foraging result in the maximum obtainable fitness (i.e., optimal foraging strategy; Abrams 1991; Lima and Bednekoff 1999; Sih 1980). Foraging opportunities that result in a
higher energetic gain often involve a greater risk of predation, injury or mortality (Houston et al. 1993). This risk-reward trade-off can lead to changes in the physiology and behaviour of individuals, social groups or even populations that can have diverse ecological consequences (Bonter et al. 2013; Matassa and Trussell 2014). These processes have been documented for predator-prey interactions (Heithaus et al. 2007; Lima and Bednekoff 1999; Matassa and Trussell 2014) and also reported for some human-wildlife interactions (Chilvers and Corkeron 2001; Ditchkoff et al. 2006; Tixier et al. 2015; Whittaker and Knight 1998). Thus, foraging behaviour has important implications in population fitness (Abrams 1991) and understanding these behavioural processes contributes to the management of interactions between wildlife and human activities, which can often be a source of conflict (Chilvers and Corkeron 2001; Ditchkoff et al. 2006; Molony et al. 2015; Whittaker and Knight 1998).

Interactions between fisheries and cetaceans are common, diverse and geographically widespread (Dawson et al. 2013; Hamer et al. 2012; Read et al. 2006; Zeeberg et al. 2006). The common bottlenose dolphin *Tursiops truncatus* (Montagu 1821) is the cetacean species most often documented in association with trawling operations, as their behavioural flexibility allows them to adapt and capitalise on a range of human activities (Fertl and Leatherwood 1997). Dolphins are known to deliberately enter nets during trawling and actively exploit fisheries for depredation (i.e., consumption of fisheries catch; Broadhurst 1998; Chilvers and Corkeron 2001; Hamer et al. 2012). A trawler effectively herds potential prey species allowing dolphins to reduce the time and effort spent foraging, thereby increasing feeding efficiency (Fertl and Leatherwood 1997; Pace et al. 2012). Although depredation may be energetically favourable for foraging dolphins (Tixier et al. 2015), increased interactions with fisheries can lead to a higher risk of injury or incidental capture (bycatch), and an increase in costs for fishers (i.e., loss of target catch and gear damage; Brotons et al. 2008; Goetz et al. 2014; Hamer et al. 2012; Read et al. 2006; Zollett and Read 2006).
Understanding the nature of the interactions between dolphins and fisheries is essential for the
development and improvement of bycatch mitigation strategies (Dawson et al. 2013;
Gonzalvo et al. 2008; Hamer et al. 2012; Waples et al. 2013). Dolphin behaviour (e.g.,
curiosity, attention, perception, social patterns and feeding) is considered a major factor
contributing toward their bycatch risk during trawling (Fertl and Leatherwood 1997).
However, there is limited information based on in situ observations of dolphin behaviour
associated with trawling operations (Broadhurst 1998; Jaiteh et al. 2013; 2014; Wakefield et
al. 2014; Wakefield et al. 2017). Most studies rely on surface observations near fishing
vessels (Chilvers et al. 2003; Cox et al. 2004; Gonzalvo et al. 2008), or on reports of gear and
catch damage that is attributed to dolphins (Fertl and Leatherwood 1997; Gazo et al. 2008;
Goetz et al. 2014).

Mitigation strategies to reduce dolphin interactions with fishing gear include the relocation of
fishing effort (e.g., time/area closures, depth limits; Fernández-Contreras et al. 2010; Goetz et
al. 2014), gear modifications (e.g., bycatch reduction devices, herein BRDs; Cox et al. 2007;
Wakefield et al. 2017), and the use of acoustic deterrents (herein pingers; Cox et al. 2004;
used to alert individuals of the presence of fishing gear to avoid entanglement (e.g., cetacean
interactions with gillnets; Dawson et al. 2013) and/or to reduce cetacean echolocation
capabilities in close proximity to fishing operations (e.g., depredation in longlines; Mooney et
al. 2009). The effectiveness of pingers to mitigate cetacean depredation and bycatch has
mostly been assessed for passive fishing methods like gillnets and longlines (Carretta and
number of experimental studies have found that pingers can be an effective measure to reduce
depredation, gear damage and cetacean bycatch in these fisheries (Barlow and Cameron 2003;
The assessment of pinger effectiveness in commercial fisheries is often difficult due to a lack of statistical power caused by the rarity of bycatch interaction events (Hamer et al. 2012), the habituation of individuals to acoustic signals (Jefferson and Curry 1996), and the variability of the effect among species and fishing methods (Dawson et al. 2013; Fertl and Leatherwood 1997; Mooney et al. 2009). For instance, the flexibility of foraging strategies and the learning capacity of bottlenose dolphins may favour their habituation to pingers (e.g., ‘dinner bell’, Dawson et al. 2013; Read et al. 2003), and the energetic gain from trawl depredation may outweigh the increased risk associated with these interactions (Houston et al. 1993; Lima and Bednekoff 1999). Early trials of pingers in trawl nets were inconclusive and have shown mixed results (Northridge et al. 2011; Stephenson and Wells 2008). However, recent advances in pinger technology may warrant reinvestigating their performance as potential dolphin deterrents in trawl fisheries (McPherson 2011; Northridge et al. 2011).

Following a detailed investigation based on extensive in situ observations of bycatch mitigation efficiencies among BRD configurations in demersal fish trawls, Wakefield et al. (2014; 2017) advised that the cause of dolphin distress leading to their capture occurred in the forward sections of the net. Thus, to further our understanding of dolphin interactions with demersal fish trawls, this study investigated in situ observations in the fore-net of commercial trawlers operating in tropical north-western Australia. This study aimed to collect quantitative data on the number, position and duration of dolphin interactions, estimates of the maximum number of individuals within the net, prey consumption rates relative to the distances ventured within the nets, and a description of social patterns and behavioural processes during day-trawls. Moreover, in order to improve the mitigation strategies for demersal fish trawl fisheries, we explored the risk-reward trade-off associated with dolphin depredation, and assessed the effectiveness of pingers to alter the behaviour of dolphins during interactions with trawlers.
Methods

Observations of dolphin interactions within the fore-net of day-trawls were recorded in the state-managed Pilbara Fish Trawl Fishery (PFTF) that operates on the tropical North West Shelf of Western Australia (i.e., between 116° and 120° E, and within depths of 50 to 100 m). The PFTF uses a single stern trawl net towed close to the substrate to target demersal scalefish (e.g., Lutjanidae, Lethrinidae and Epinephelidae) with the allocated annual trawl effort consolidated onto three full-time vessels during the period of the study (~8,220 hours of trawl effort in 2013; Newman et al. 2015). The use of BRDs (an inclined grid and escape hatch) has been mandatory in this fishery since 2006 and has resulted in much lower records of dolphin bycatch (Mackay 2011; Stephenson and Wells 2008; Wakefield et al. 2014; Wakefield et al. 2017). Nonetheless, dolphin interactions with trawl nets for depredation are very common (Jaiteh et al. 2013; Wakefield et al. 2014; Wakefield et al. 2017). In this study, the common bottlenose dolphin (Tursiops truncatus) was the only marine mammal observed to interact with trawl nets (herein referred to as dolphins).

Video cameras were deployed during 50 commercial day-trawls in January and February 2013. The cameras were positioned at one of two distances from the headline (i.e., net opening) of the demersal fish trawl nets to obtain in situ underwater observations of dolphin interactions (Fig. 1). The first camera position was at the junction of the first and second body panel sections, ~11 m from the headline facing forward (i.e., looking upstream), with the opening of the net within the field of view (n = 19 day-trawls). The second camera position was at the junction of the second and third body panel sections, ~25 m from the headline, also facing upstream (n = 31 day-trawls; Fig. 1). In both locations the cameras were attached
inside the nets on the upper panel in a central position, so that the width of the net remained within the field of view.

Filming was limited to hours of natural illumination (0830 – 1630 h) to avoid the use of artificial lights that could modify dolphin behavior from standard commercial operations. Net cameras (GoPro Hero2™) were set to record in standard definition (720 pixels of vertical resolution, progressive scan and 25 frames per second) to reduce the file size, and were fitted with a second battery (GoPro BacPac™) and a large capacity storage card (64 GB SD class 10) to achieve full coverage of the longest trawls (up to 4 h). Net cameras were placed in waterproof housings (Sartek Deep Housing™) that were rated to 200 m depth, which was greater than the depths trawled by the PFTF (i.e., 50-100 m).

Details of all trawls sampled were recorded in statutory logbooks by fishers (e.g., vessel, latitudes and longitudes, times, depths, catches), and validated against each vessels independent satellite-based monitoring system (VMS) and onboard electronic observer program from a concurrent study (see Wakefield et al. 2014; Wakefield et al. 2017). Videos were analysed using the software Event Measure (version 3.32, SeaGIS Pty Ltd) to collect quantitative data on dolphin interaction dynamics (i.e., time of dolphin arrival during trawling, interaction duration, position, number of dolphins) and their associated behaviours (e.g., foraging, social). Each dolphin observed was recorded as an individual interaction, with durations recorded from the moment the dolphin entered the cameras field of view, until it exited. Interactions were categorised into the three main periods associated with trawling operations, i.e. deployment, trawling or hauling. Observations of dolphins on the outside of the net occurred on the periphery of the cameras field of view, and thus only a portion of these interactions could be observed which provided limited information toward subsequent analyses. The position within the trawl nets for each dolphin interaction was determined...
relative to the location of the camera (i.e. forward or behind) and categorised into one of three
groups (see Fig. 1). These categories included: (A) forward of the camera located at the
junction of the first and second body panels (i.e., < 11 m from the headline within the net);
(B) forward of the camera located at the junction of the second and third body panels (i.e., 11-
25 m from the headline); or (C) behind the camera at the latter body panel junction (i.e., > 25 m from the headline; see Fig. 1). The estimated widths of the net during trawling at each of
these three locations decreased from 13.6 m at the headline, to 9.1 m at the first net junction,
to 3.4 m at the second net junction (Fig. 1). The risk of capture was, logically, presumed to
increase with the distance an individual dolphin ventured inside the net during trawling. The
bycatch risk associated with dolphin interactions in these positions was considered negligible
for dolphins outside the net (O), low for interactions that occurred in the net opening (A),
medium for interactions that occurred in the second body panel section (B) and high for all
interactions that occurred behind the second body panel (C). However, it is important to note
that despite this increasing inherent risk, dolphin bycatch in this trawl fishery is a relatively
rare event (i.e., 5.2 dolphins per 1,000 trawls in 2012; see Wakefield et al. 2014). Dolphins
that were observed to enter the trawl net but did not exit back through the forward opening
were considered to have interacted with the exclusion device. These interactions were
assumed to have resulted in an exit through the escape hatch underwater if the dolphins were
not retained in the catch (i.e., bycatch), which was confirmed from a concurrent video-based
independent observer program onboard the vessels (Wakefield et al. 2014). The fate of these
bycaught dolphins were considered to be ‘returned alive’ if they displayed conspicuous active
movements prior to release. However, it must be noted that the fitness and survival rates of
these individuals after being returned alive is unknown.

Additional information recorded for each dolphin interaction included the number of foraging
attempts, prey consumption and social interactions with other dolphins (e.g., aggression or
females with calves). Individuals were described as foraging when they were observed chasing or catching prey, and consumption of prey was recorded when dolphins were observed eating their catch or with the prey in their mouth. The consumption values for dolphins recorded from position C of the trawl net (behind the second body panel section) were considered a conservative estimate as only dolphins swimming past the camera with prey in their mouth could be counted. Occasionally, individual dolphins were identified based on unique external characteristics (n = 18), which facilitated records of repeated interactions within the same trawl or multiple trawls.

Dolphin interaction rates (i.e., number of interactions per day-trawl minute) and durations in the forward sections of the trawl nets were compared between deployments with (n = 14) or without (n = 17) pingers (i.e., Dolphin Dissuasive Device DDD 03H, STM Products SRL) to assess their effectiveness in dissuading dolphin behaviour. Two pingers were deployed either side of the cameras for redundancy in case one malfunctioned, with sound emissions from the pingers recorded by the cameras speakers used to confirm functionality. According to the manufacturer, the pingers emissions are unidirectional with a random ultrasound frequency that oscillates between 2-500 KHz with a forward projection range of up to 80 m within a circular cone that is 300 m in diameter. Thus, this would provide ample coverage of the entire opening of the trawl net (13.6 m wide by 4.0 m high). Only interactions recorded inside the nets and from cameras deployed at the second net panel junction were included in these analyses. The mean interaction rate observed from day-trawls with pingers present or absent was compared using a two-sided t-test (independent samples). The Shapiro-Wilk test of normality indicated that the assumption that the data were derived from a normal distribution was valid (pingers present: W = 0.9438, p = 0.4688; pingers absent: W = 0.9087, p=0.09517), and Levene’s test was not significantly different indicating homogeneity of variances (equal variances) across samples (F = 0.0108, p = 0.9178).
The potential for the duration of dolphin interactions to be shorter when pingers were present was assessed using a randomisation test. Permutations provided an efficient approach to testing, as the data did not conform to the distributional assumptions of normality. As a consequence of the skewed nature of the data, the median was chosen as a test statistic. The group allocations (i.e., pingers present or absent) of the sample observations were randomised 10,000 times and the difference in medians calculated, thereby generating a probability distribution of the test statistic (i.e., difference in medians). The proportion of these 10,000 differences that were equal to or less than the difference between the median duration of interactions for the original samples, where pingers were either present or absent, was then calculated. If this proportion ($p$) was $\leq 0.05$, it could be concluded that the average duration of interactions was significantly less with pingers present than when pingers were absent during day-trawls.

**Results**

Net cameras deployed during 50 demersal day-trawls on two fishing vessels logged a total of 104.65 hours of video footage with 5,908 dolphin interactions recorded (i.e., $\mu = 118.16 \pm 15.87$ SE interactions per day-trawl; Table 1). Dolphins were observed in close proximity to nets in 98% of day-trawls and individuals entered the nets during 90% of these trawls. The cameras deployed at the first body panel section during 19 day-trawls recorded on average 91.21 ($\pm 20.31$ SE) dolphin interactions per day-trawl in and around the net opening. While cameras deployed at the second body panel during 31 day-trawls recorded more dolphin interactions per trawl (i.e., $\mu = 134.68 \pm 22.09$ SE; Table 1).

The number of interactions per day-trawl recorded from both camera locations was higher outside than inside the trawl net (Table 1). Inside the net, most dolphins were observed to position themselves in the second body panel (i.e., position $B$; 91.3%, Fig. 2). A smaller
proportion of dolphins remained in the net opening (4.7 %, position A) or positioned themselves deeper in the trawl net, behind the second panel (4.0 %, position C). The average duration of interactions and dolphin arrival times during trawling differed among each of the positions in the net (Fig. 2). Dolphins remained in the net longer during interactions that occurred deeper within the net (µ = 3.1 min ± 0.5 SE, position C; Fig. 2), while only short interactions (< 2 min) were recorded in the net opening (µ = 0.4 min ± 0.1 SE, position A; Fig. 3). The longest interaction duration recorded occurred outside the net (10.4 min), with the longest interaction inside the net being 7.7 minutes for a dolphin that ventured ~25 m within the trawl net. Dolphins that remained outside the net had on average the earliest arrival times while, inside the net, the earlier arrival times were recorded for dolphins that transitioned straight through to the second body panel (Fig. 2).

The consumption of fish per interaction increased exponentially the deeper in the net the dolphin interactions occurred (Fig. 2). The consumption rates estimated for position C of the trawl (i.e., µ = 0.5 min ± 0.2 SE fish consumed per interaction) were the highest despite this being a conservative estimate, as only dolphins swimming out from behind the camera with fish in their mouth were counted. The maximum number of dolphins observed in the trawl net at the same time (i.e., MaxN) varied markedly from 2 dolphins in position A (µMaxN = 1.1 dolphins per trawl ± 0.1 SE), to 11 dolphins in position B (µMaxN = 4.1 dolphins per trawl ± 0.4 SE), to 3 dolphins in position C (µMaxN = 1.6 dolphins per trawl ± 0.3 SE; Fig. 2).

There were 18 individual dolphins identified from unique external characteristics. These dolphins were observed during 123 interactions inside the net with up to 18 interactions per individual (µ = 6.8 interactions per dolphin ± 1.34 SE). Half of these dolphins (n = 9) were recorded interacting in more than one trawl and some were present during trawls on consecutive (n = 2) or non-consecutive days (n = 3). One of these dolphins was recorded in 8
different trawls over 4 different fishing days. Further, groups of two or three of these dolphins (n = 3 groups) were recorded together on more than one occasion; one pair of dolphins were recorded on two consecutive days and, one pair and a group of three dolphins were recorded in numerous trawls within the same day. The most common social interaction observed involved pairs of dolphins swimming with their ventral surface in close proximity to each other (i.e., navel-to-navel), with two of these interactions observed in position B, one interaction in position C, and nine interactions recorded outside the net (position O). Nine interactions involving aggressive behaviour (e.g., chasing and bitting) from larger dolphins towards smaller dolphins were observed in positions A and B of the trawl. There were two records of a mother and calf swimming together in close proximity on the outside of the trawl net.

Only four of the 5,908 dolphin interactions (0.07 %) involved a dolphin passing behind a camera and not returning, thus interacting with the BRDs that were positioned ~34 m from the headline within the trawl net. Two of these interactions were presumed to have resulted in the underwater expulsion of the dolphin through the escape hatch, as they were not observed by the deck cameras (i.e., above water observer program). Additionally, two of these interactions occurred while the net was being hauled, which resulted in short subsurface interaction durations (i.e., < 6 min) and the dolphins escaping or being released alive. For the two interactions with the BRDs that occurred during trawling, one involved a dolphin swimming behind the camera while chasing a school of small fish, and the other a dolphin swimming slowly (less than the speed of the trawl) for unknown reasons.

The effect of pingers to dissuade dolphin interactions in the forward sections of the trawl nets was assessed based on comparisons between both their interaction rates and interaction durations. When pingers were present, the mean interaction rate of dolphins was higher (μ =
0.7 interactions per day-trawl minute ± 0.1 SE) than when pingers were absent (µ = 0.4 ± 0.1 SE). However, the t-test resulted in insufficient evidence at the alpha level (α = 0.05) to suggest that these differences in dolphin interaction rates between the presence or absence of pingers in day-trawls were statistically significant (t = 1.71, p = 0.097, d = 0.618). The power of the two-sided t-test to detect an effect of this size is approximately 38 %. A post hoc power analysis revealed that a sample size of ~25 trawls in each group would be needed to detect a large effect size (d = 0.8, indicating an approximate two-fold difference) to obtain sufficient statistical power at the recommended 0.8 level (Cohen 1988). Moreover, the median (and mean) duration of dolphin interactions observed was shorter for day-trawls that had pingers present (Table 2). The randomisation test resulted in only 756 of the 10,000 random assignments leading to a difference between medians being less than the observed difference (i.e., -0.1125; Table 2). Thus, under the assumption of no pinger effect, the chance of seeing a difference of -0.1125 or less was 7.6 %. Therefore, there was insufficient statistical evidence (at α = 0.05) to attribute any observed difference in the number and duration of dolphin interactions to the effect of the pingers.

Discussion

Underwater observations within demersal fish trawl nets during commercial operations confirmed that dolphin interactions were extremely common (i.e., 98 % of day-trawls; 5,908 interactions from 50 day-trawls), but that most interactions occurred outside of the net (> 78.3 %). Dolphins actively used these trawls to optimise foraging and were observed easily outswimming the slow moving trawls (e.g., average speed ~2-3 knots), which allowed them to venture and forage more than 25 m into the trawl net. The vast majority of dolphin interactions inside the net occurred in the second body panel that was ~11-25 m from the headline (position B, 91.3 %), compared to immediately inside the net (position A, 4.7 %) or
deeper in the net (position C, 4.0 %). Despite this second body panel being relatively narrow (~9 m high by 3 m wide, see Fig. 1), there were up to 11 dolphins observed foraging in this area at the same time. The interaction durations and the consumption of prey increased markedly with the increased distance that dolphins ventured inside the trawl nets. Durations of dolphin interactions within and around the trawl nets (maximum interaction duration of 7.7 min inside and 10.4 min outside) were sometimes close to the limits of their breath holding capabilities (i.e., reported to be around 7 to 12 minutes; Ridgway et al. 1969; Schreer and Kovacs 1997). The unprecedented detail of quantitative data collected from these in situ observations on the nature of dolphin interactions in the forward sections of the trawl nets (i.e. from the net opening to third body panel ahead of the BRD panel) provided a unique opportunity to better understand their interaction dynamics and to assess current and future bycatch mitigation strategies.

Optimal foraging strategy theory suggests that organisms can balance the need to feed efficiently and to avoid injury or predation in order to achieve maximum fitness (Abrams 1991; Sih 1980). This balance is important as foraging opportunities with higher energetic gain often involve greater risk (Houston et al. 1993; McNamara and Houston 1994). Interestingly, despite the increased risk of dolphin injury or bycatch in the deeper sections of the trawl nets, this part of the trawl is where the interaction durations were longest and prey consumption was highest. This risk-reward trade-off is consistent with the predation-risk allocation hypothesis (Lima and Bednekoff 1999). As such, fishing operations influence dolphin behaviour by providing the opportunity to maximise energy intake, similar to the known effect that predation risk has on prey foraging behaviour (Houston et al. 1993; Matassa and Trussell 2014). The identification of a small number of dolphins (i.e., 18 identified individuals, including one pair and a group of three) repeatedly observed together during different trawls and sampling days suggests that this foraging behaviour is a specialised
strategy among groups that have effectively balanced the conflicting costs (bycatch risk) and benefits (energetic gain, Chilvers and Corkeron 2001; Pace et al. 2012). However, the number of different groups that may exhibit this trawler associated foraging strategy was not able to be determined from this study. Other individuals in the population that have not learnt this behaviour may remain at the net opening or on the outside of the trawl where they obtain less reward but at a much lower risk (e.g., dolphins outside the nets sometimes feed on prey that escape or that is trapped in the mesh), or other dolphins in the area may not interact with trawlers at all (Broadhurst 1998; Chilvers et al. 2003).

Bottlenose dolphins are known to learn and transfer foraging methods via social learning and local tradition (Fertl and Leatherwood 1997; Pace et al. 2012). Some social interactions reported during this study involving aggressive behaviour of adult dolphins towards younger individuals, or the presence of females with calves in the proximity of trawl nets might infer some form of social learning. Our observations suggest that dolphin depredation in trawls was an energetically favourable trade-off for foraging except when (1) individuals performed high-risk behaviours (e.g., entering the trawl net during hauling, residing deep within the trawl net for extended periods or social aggression), or (2) fishing gear became unstable (e.g., net hooked up on the benthos or vessel turning sharply during trawling causing otter boards to collapse impeding the net opening).

Despite very high numbers of dolphin interactions with trawl nets, interactions with the BRDs were extremely rare (i.e., 4 out of the 5,908 dolphin interactions, 0.07 %). Two interactions with the BRDs resulted in the rapid expulsion of the individual through the escape hatch, with a suspected high probability of survival based on its interaction duration. During this study, only one interaction resulted in the death of a dolphin, but the exact cause could not be determined as the dolphin was already lethargic by the time it entered the field of view of the
camera located ~25 m inside the net. However, during this interaction there was no evidence that the fishing gear malfunctioned (i.e., otter-boards collapsed or the gear hooked-up on the benthos). From the detailed information described in this study we can infer that the primary causes contributing to dolphin bycatch in trawl nets are associated with (1) dolphin behaviour and/or (2) fishing gear stability.

Acoustic deterrents are a bycatch mitigation device increasingly used in global fisheries to reduce cetacean interaction rates with fishing gear (Dawson et al. 2013). However, the newly designed pingers assessed in this study were ineffective at reducing rates or durations of dolphin interactions with demersal fish trawls. Pingers have been more effective for reducing cetacean bycatch in passive (e.g. gillnets, Kraus et al. 1997; Waples et al. 2013) than active fishing gear (e.g. trawls, Fertl and Leatherwood 1997; Northridge et al. 2011; Stephenson and Wells 2008). The effectiveness of bycatch mitigation devices for cetaceans are typically difficult to determine due to limited statistical power associated with the rarity of bycatch events (Dawson et al. 2013; Hamer et al. 2012). However, although dolphin bycatch rates were very rare in this study, the number of interactions was very high and provided no evidence for behavioural changes through the use of pingers. Nonetheless, the results of this study should not deter the evaluation of the effectiveness of future advances in acoustic or other types of deterrents.

Cetacean interactions with trawl fisheries appear unavoidable, particularly in areas where individuals have established depredation behaviours. As such, bycatch mitigation may be more effective by creating a safer environment for dolphins in the fore-net of demersal fish trawls by improving the stability of trawl gear during fishing. In response to the findings of this and a concurrent study (Wakefield et al. 2017), otter-board sensors have been implemented on all PFTF vessels to monitor their orientation and stability during fishing.
Wildlife-human interactions are increasingly common and often represent a source of conflict that requires management intervention (Hebblewhite and Merrill 2008; Whittaker and Knight 1998). Interactions between cetaceans and fisheries offer an interesting example of the benefits and impacts in the relationship between wildlife and human activities (Chilvers and Corkeron 2001; Tixier et al. 2015). The findings in this study advance our understanding of the nature and extent of cetacean interactions in demersal fish trawls, and concludes that mitigation strategies aimed at creating a more stable environment within the fore-net of fish trawls are likely to be more effective than trying to alter dolphin behaviour to avoid fishing gear.

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References.


Chilvers, B.L., Corkeron, P.J., and Puotinen, M.L. 2003. Influence of trawling on the behaviour and spatial distribution of Indo-Pacific bottlenose dolphins (Tursiops aduncus) in
Moreton Bay, Australia. Canadian Journal of Zoology-Revue Canadienne De Zoologie


McPherson, G. 2011. Acoustic methods to mitigate bycatch and depredation by marine mammals on commercial fishing operations in Australian waters: Fishermans options, Gold Coast, Australia.


Table 1. Summary of the number of trawls sampled and dolphin interactions recorded by net cameras deployed at the end of the first or second body panels in the trawl net. Interactions are classified based on the position of the dolphins in the trawl net, i.e., outside the trawl net (O), immediately inside the net opening (A), at the second body panel (B) and behind the second body panel (C).

<table>
<thead>
<tr>
<th>Camera location</th>
<th>Number of trawls</th>
<th>Interaction position</th>
<th>Distance from headline</th>
<th>Total number of interactions</th>
<th>Interactions per trawl Mean ±SE</th>
<th>Proportion of interactions*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel 1</td>
<td>19</td>
<td>Outside O</td>
<td>-</td>
<td>1078</td>
<td>56.74 ± 14.26</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inside A</td>
<td>&lt; 11 m</td>
<td>31</td>
<td>1.63 ± 0.36</td>
<td>4.73</td>
</tr>
<tr>
<td>Panel 2</td>
<td>31</td>
<td>Outside O</td>
<td>-</td>
<td>3058</td>
<td>98.65 ± 18.53</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inside B</td>
<td>11 - 25 m</td>
<td>1070</td>
<td>34.52 ± 7.38</td>
<td>91.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>&gt; 25 m</td>
<td>47</td>
<td>1.52 ± 0.72</td>
<td>4.01</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>**</td>
<td></td>
<td>5,908</td>
<td>118.16 ± 15.87</td>
<td>91.26</td>
</tr>
</tbody>
</table>

* Proportion of interactions recorded inside the net on each position of the trawl (%).
** Total includes data on the positions above plus interactions behind the camera of the first panel (B+C).

Table 2. Comparison of the duration of dolphin interactions in fish trawls with pingers present or absent.

<table>
<thead>
<tr>
<th>Pinger</th>
<th>Sample Size</th>
<th>Mean ±SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>457</td>
<td>1.68 ±1.43</td>
<td>1.08</td>
</tr>
<tr>
<td>Absent</td>
<td>656</td>
<td>1.29 ±1.02</td>
<td>0.97</td>
</tr>
</tbody>
</table>
Figure Captions

Figure 1. Schematic diagram of the trawl net (modified from Wakefield et al. 2017) showing the camera locations (black triangles, junctions of the first, second and third body panels), and the positions where dolphin interactions occurred categorised by each body panel section, i.e. (A) first, (B) second and (C) third. Position A included interactions in front of camera 1, and positions B and C were forward or behind camera 2, respectively. Position O refers to interactions outside of the trawl net.

Figure 2. Summary statistics of dolphin interactions recorded from three different positions within the trawl nets (see Fig. 1), including within the first body panel (A, < 11 m from headline), within the second body panel (B, 11-25 m) and behind the second panel (C, > 25 m). Error bars show standard error.

Figure 3. Frequency distribution of dolphin interaction durations from three different positions within the demersal fish trawl nets (see Fig. 1), including within the first body panel (A, < 11 m from headline), within the second body panel (B, 11-25 m) and behind the second panel (C, > 25 m).
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