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Assessing interactions between dolphins and small pelagic fish on branchline to design a depredation mitigation device in pelagic longline fisheries

Njaratiana Rabearisoa[1]*, Pascal Bach[2], and Francis Marsac[3]

[1]*Institut de Recherche pour le Développement, UMR 212 EME, Représentation de la Réunion, 2 rue Joseph Wetzell, CS 41095, 97495 Ste Clotilde CEDEX, La Réunion, France*

[2]*Institut de Recherche pour le Développement, UMR 212 EME, Avenue Jean Monnet, CS 30171, 34203 Sète Cedex, France*

[3]*Institut de Recherche pour le Développement, UMR 212 EME, University of Cape Town, Department of Oceanography, Private Bag X3, Rondebosch 7701, South Africa*

**Corresponding author: tel: +262 692 98 22 09; e-mail: njaratiana.rabearisoa@gmail.com*

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Depredation by false killer whales (*Pseudorca crassidens*) and short-finned pilot whales (*Globicephala macrorhynchus*) in pelagic longlining is an issue leading to negative impacts on the economics of the fishery and on odontocetes themselves. We investigated the efficacy of a new depredation mitigation device called "DEPRED" in the interaction between bottlenose dolphins (*Tursiops aduncus*), spinner dolphins (*Stenella longirostris*), and small pelagic fish (SPF) attached to branchlines to simulate caught fish. We suggest implications for DEPRED efficacy with larger toothed whales interacting with pelagic longline capture in the open ocean. The design of the device uses streamers to both deter cetaceans and protect fish from predation. In controlled experiments, we tested its efficacy by observing changes in the dolphin's behaviour brought on by the presence or absence of the device on branchlines. First, dolphin–SPF interactions were observed at the small scale using video footage recorded with an underwater camcorder. Second, the efficacy of the device was quantified from interactions between dolphins and 80 branchlines deployed on a longline 500 m long baited with SPF. One half of the SPF on successive branchlines was protected by DEPRED and the other half was not. A total of 707 branchlines were set when dolphins interacted with SPF, and among them, 355 were equipped with DEPRED. Encouraging results were obtained: over the short term, the number of damaged unprotected SPF was on average more than twice the number of protected ones. Nevertheless, habituation behaviour was observed for a resident group of *T. aduncus* in the experimental area. The relation between the deterrent effect of the device and constraints related to the design of such a device to be used at a commercial operational level are discussed.

Keywords: bottlenose dolphin, Cramer's *V* statistic, deterrent effect, mitigation measures, physical protection, spinner dolphin.

Introduction

Depredation, the damage or removal of captured fish from fishing gear by marine predators, is a worldwide issue affecting diverse fisheries and involving various marine predators, such as toothed whales, sharks, squids, and birds. Toothed whale depredation is one of the biggest challenges faced by longline fisheries. For instance, demersal longline fisheries targeting Patagonian toothfish (*Dissostichus eleginoides*) or sablefish (*Anoplopoma fimbria*) are impacted by killer whale (*Orcinus orca*) and sperm whale (*Physeter macrocephalus*) depredation. As for pelagic longline fisheries targeting tuna (*Thunnus* spp.) and swordfish (*Xiphias gladius*), toothed whale depredation mainly involves killer whales, false-killer whales (*Pseudorca crassidens*), and pilot whales (*Globicephala* spp.). Yet mechanisms explaining how toothed whales interact with captured fish on this gear still remain an enigma (Mooney *et al.*, 2009). Whereas toothed whale depredation impacting demersal longline fisheries is broadly documented (Yano and Dahlheim, 1995; Nolan *et al.*, 2000; Donoghue *et al.*, 2002; Hucke-Gaete *et al.*, 2004;

Sigler *et al.*, 2008; Clark and Agnew, 2010; Peterson *et al.*, 2013), only few scientific papers deal with this interaction in pelagic longline fisheries (Sivasubramanian, 1964; Dalla Rosa and Secchi, 2007; IOTC, 2007; Ramos-Cartelle and Mejuto, 2007; Hamer *et al.*, 2012). Depredation can have adverse conservation impacts on odontocete populations since fishers can adopt harmful methods to mitigate those interactions (Dalla Rosa and Secchi, 2002; Hucke-Gaete *et al.*, 2004) and individuals involved in the process can be accidentally caught and released injured or dead (Kock *et al.*, 2006; Garrison, 2007; Kiszka *et al.*, 2009; Forney *et al.*, 2011). For those species classified as "Data Deficient" in the IUCN Red List of "Threatened Species" (Taylor *et al.*, 2008a, b), even if the impacts of those negative interactions on their ecology are unknown, they are likely more worrisome for small and/or isolated populations, such as the island-associated ones (Baird *et al.*, 2010).

Depredation also has negative impacts on the economic profitability of pelagic longline fleets, with depredation rates (DRs) on target species ranging from 0.2 to 45% depending on the catch resolution (annual catch or catch per fishing operation; Nishida and Shiba, 2003; Monteiro *et al.*, 2006; Dalla Rosa and Secchi, 2007; Hernandez-Milian *et al.*, 2008; Romanov *et al.*, 2013).

Thus, addressing and deterring depredation is paramount (Gilman *et al.*, 2006a). Some depredation mitigation measures (DMMs), mostly involving active acoustic devices, have been tested so far in various fisheries. Although they have been shown to be effective over the short term, their potential negative acoustic impacts on the ecosystem should not be ignored (Kraus *et al.*, 1997; Bordino *et al.*, 2002; Cox *et al.*, 2004; Berrow *et al.*, 2008; López and Mariño, 2011). Additionally, owing to the learning skills of toothed whales, the acoustic signal may become a positive cue allowing them to locate the fishing gear (Jefferson and Curry, 1995; Brotons *et al.*, 2008). Other toothed whale DMMs proposed for pelagic longline fisheries include modifications of fishing methods (Gilman *et al.*, 2006a), fleet communication (Gilman *et al.*, 2006b), attenuation of acoustic cues to reduce the ability of the toothed whales to detect the fishing gear (McPherson *et al.*, 2003), avoidance of chumming and offal discards, and use of both decoy fishing tactics and deterrent fish for toothed whales (Gilman *et al.*, 2006a). However, the efficacy and potential side effects of all of those methods still need to be assessed.

The aforementioned DMMs can be defined as preventive tools, but other DMMs are classified as protective measures and are designed to physically protect the captured fish. They focus on the terminal step of the depredation process, once the interaction with predators has been initiated. Their principle consists of setting a physical barrier between the fish and the predator to protect the catch (Hamer *et al.*, 2012; Rabearisoa *et al.*, 2012). Several physical devices were successfully used to deter bottlenose dolphins in troll fisheries (Zollett and Read, 2006), and killer whales and sperm whales in demersal longline fisheries (Moreno *et al.*, 2007, 2008; Pin and Rojas, 2007; Pshenichnov and Zaitsev, 2007; Goetz *et al.*, 2011).

Unlike fish captured by demersal longline fisheries in high latitudes, tropical pelagic longline caught fish are exposed to toothed whale depredation during the whole soaking time as predators and target fish occupy the same depth strata (Moreno *et al.*, 2008). The device deployment should therefore be triggered when the fish gets hooked. Previous studies suggested that odontocetes may be deterred by tangles in the fishing gear that would prevent them from accessing the hooked fish (Hamer *et al.*, 2012) as they would be scared to be injured or entangled (Kock *et al.*, 2006; Zollett and Read, 2006). Tunas caught and entangled by fishing gear would therefore be less prone to depredation (Nishida and Tanio, 2001; McPherson *et al.*, 2003). Building on successful physical DMM tests obtained for both demersal longline and troll fisheries, and valuable insights provided by trials of physical DMM in pelagic longline fisheries (Hamer and Childerhouse, 2012; Rabearisoa *et al.*, 2012), we present results of at-sea tests of a new device called "DEPRED" (DEPREDation mitigation device by preventing predator attacks and protecting capture).

To date, existing devices aiming at deterring depredation such as "spiders ", and "net sleeves" (Rabearisoa *et al.*, 2012), or "chain" or "cage" devices (Hamer and Childerhouse, 2012) are designed to introduce a simple physical barrier between the caught fish and marine mammals. Compared with these devices, the DEPRED employs a physical barrier to protect the fish from odontocetes and streamers to deter predators from approaching the catch. When developing a technology dealing with wild animals, one aims to scrutinize the behaviour of targeted individuals to shape the technology design to obtain expected responses before considering potential operational constraints. Captive animals (or more accessible populations) have already been used in previous studies to address broader questions regarding the species' behaviour. For instance, Mooney *et al.* (2009) studied the effects of an acoustic device designed to deter false killer whale depredation on a trained false killer whale to give some insights into longline bycatch and depredation.

Toothed whales are known to use their visual and echolocation abilities to detect their prey and discriminate its size, thickness, and material composition (Au, 1993). Since depredation can also occur at night where visual cues cannot be invoked (Read, 2007; Romanov *et al.*, 2007; McPherson *et al.*, 2008), echolocation is likely to be an essential component of the depredation process. Furthermore, it appears that despite their morphological and behavioural differences, there are some similarities in echolocation strategy between common bottlenose dolphins (*Tursiops truncatus*) and false killer whales. Indeed, it appears that both species pay attention to the same frequency range when they perform a similar discrimination task (Ibsen *et al.*, 2011). Therefore, although the DEPRED tests presented in this study assessed interactions between small delphinids and small pelagic fish (SPF), we assume that the behaviour of larger toothed whales, such as short-finned pilot whales or false killer whales, towards large fish (tunas, billfish) protected by the DEPRED, would be fairly similar.

The main purpose of the present study was to get first insights into the behavioural response of delphinid species towards the DEPRED and to collect longitudinal data during experimental fishing trials to estimate the DEPRED efficacy over time. We examined interactions between Indo-Pacific bottlenose dolphins (*Tursiops aduncus*), spinner dolphins (*Stenella longirostris*), and SPF in a near shore and easily accessible area around Reunion Island (Southwest Indian Ocean) to understand how the DEPRED works and to plan the deployment of the DEPRED at a larger scale, on longlines depredated by large toothed whales. Finally, we discuss technical aspects and essential improvements needed before undertaking any DEPRED trials aboard professional longliners.

Material and methods

The DEPRED device has two goals: (i) to startle predators when they are close to the gear and (ii) to protect captured fish. The DEPRED prototype consists of eight 1 m long streamers made of tarpaulin material and fixed on a 2 cm diameter PVC tube (Figure 1). Four

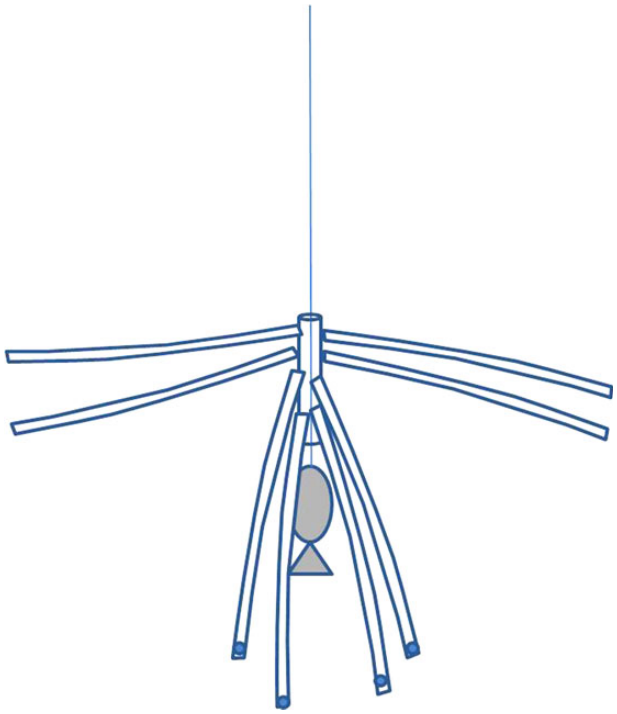

Figure 1. The DEPRED (DEPREDation mitigation device by preventing predator attacks and protecting capture) is a depredation mitigation device made up of eight streamers. Upper ones freely move around the fish (deterrent affect) and lower ones are weighted, covering the fish (protective effect).

streamers were designed to deter odontocetes and prevent them from depredating fish by freely moving with currents and turbulence, and four others were weighted and served to physically protect the mackerel used as SPF attached at a branchline extremity to simulate caught fish. The deterrent effect of the first four streamers was inspired by tori lines (or bird-scaring devices) deployed by longliners and aimed at mitigating the incidental capture of foraging seabirds attempting to feed on baited hooks (Keith, 1999; Løkkeborg, 2011). Like seabirds, odontocetes might exhibit an aversion behaviour to flapping streamers.

DEPRED tests were carried out in Baie Saint Paul (Reunion Island) aboard a small artisanal fishing boat (Figure 2). We restricted our study area to coastal waters (up to 60 m deep) where resident groups of two delphinid species, the bottlenose and the spinner dolphin, occur frequently (Dulau-Drouot *et al.*, 2008). Based on photo-identification and visual observations, the pod of bottlenose dolphins was identified as a unique group of ~12 individuals that was present for both experimental trials carried out in 2010 and 2011. Moreover, the selection of this experimental area is due to the low abundance of other large pelagic predators such as turtles, rays, sharks, wahoo, dolphinfish, and large carangids. Due to the low abundance of other pelagic predators, we attributed all depredated fish to dolphins. A typical experimental trial started by setting the branchlines with SPF in the water, some without DEPRED (control branchlines) and some with DEPRED (treatment branchlines).

Assessment of DEPRED efficacy based on dolphin interactions with platforms

To assess dolphin interactions, we built PVC platforms of 1 m^2 maintained at the sea surface by four buoys. One monofilament nylon branchline 5 m long was attached to each corner of the platform. The platforms were equipped with a video camcorder enclosed in a waterproof housing and fixed to the centre of the frame. The focus was wide enough to record the behaviour of predators interacting with fish and devices immediately below (Figure 3). The branchline was inserted into the tube carrying eight streamers, and an SPF was tied at its end through the mouth and gills by a knot to simulate a caught fish. No hook was used to prevent dolphins from being injured.

One experimental trial consisted of setting two platforms 20 m apart. Some platforms were deployed without (control platform) and with (treatment platform) the DEPRED on branchlines. For a given platform, all branchlines had the same status (treatment or control).

Data collection included recording the position of the platforms in the bay, characteristics of dolphin pods (size, species, and physical particularities of some individuals), and the SPF status of branchline (intact, partially removed, totally removed). Underwater video footages of ~90 min duration per platform set were analysed at the end of each trial. This first survey was mainly to assess the behaviour of dolphins interacting with the DEPRED and to get first estimates of the efficacy of the device.

Assessment of the DEPRED efficacy based on dolphin interactions with an experimental pelagic longline

The devices were deployed along a 500 m long mainline arranged in two parts of 40 branchlines each, protected and not protected by the DEPRED. The first half of the mainline was equipped with 40 unprotected branchlines (control). The second half was equipped with 40 protected branchlines (treatment). SPFs were tied on the branchlines through the mouth and the gills by a knot. The distance between branchlines was 5 m and a buoy was deployed every 20 m to maintain the mainline at the surface. The prototype deployed during the first survey was slightly modified by adding plastic hollow balls at the end of the upper streamers to increase their buoyancy, and brass solid balls at the end of the lower streamers to weight them.

The beginning of the longline setting started at 7.00 a.m. and lasted ~30 min. The beginning of the hauling started between 12.00 p.m. and 2.00 p.m., and lasted ~90 min. For each longline experiment, the fish status (intact, partially removed, totally removed) was recorded after dolphin–longline interactions. The efficacy of the DEPRED was assessed by the comparison of the DR between experimental sets. DR was defined as the ratio between the number of depredated fish and the total number of fish deployed in the experiment. It was calculated for each set of branchlines (treatment or control).

Data processing was performed on 2 × 2 contingency tables: one table per longline summarizing the number of depredation attempts for each treatment and control. For each table, a Pearson χ^2 test was performed to test the hypothesis of similarity of interactions between protected vs. unprotected branchlines. Additionally, the Cramer's *V* coefficient (Cramér, 1980) was calculated for the successive cumulated results of experiments for each dolphin species. This coefficient is based on χ^2 and measures the strength of the association between nominal variables. It ranges from 0 (no association) to 1 (strongest association between variables). In our study, it describes the trend of the cumulative association between depredation and protection for each dolphin species. Statistical analyses were performed with the lsr package in R (lsr V 0.1.1, 2012—R Development Core Team, version 2.12.2).

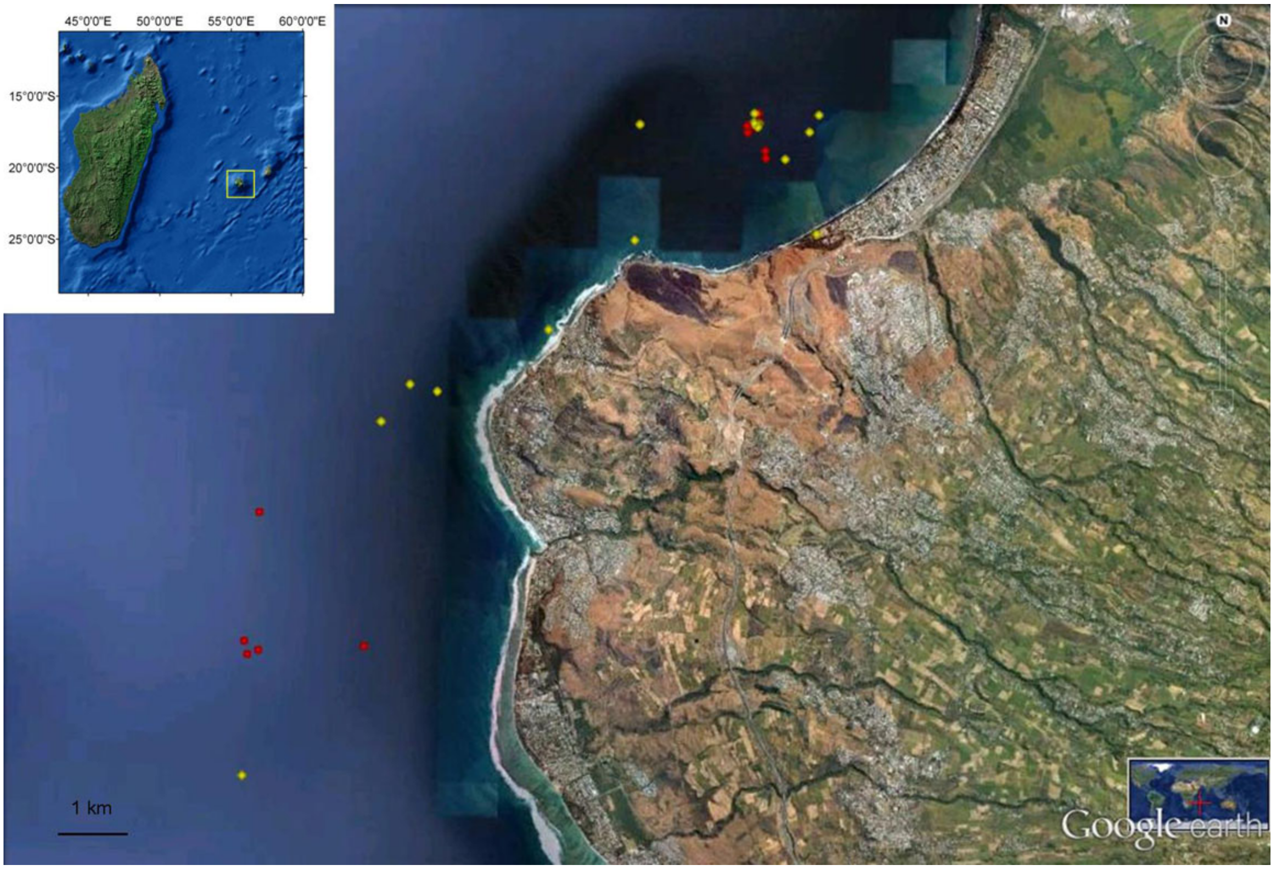

Figure 2. The study area extended from St Gilles les Bains harbour to Saint Paul (map obtained with Google Earth©). Yellow dots represent device setting without dolphin interaction. Red dots represent device setting with dolphin interaction.

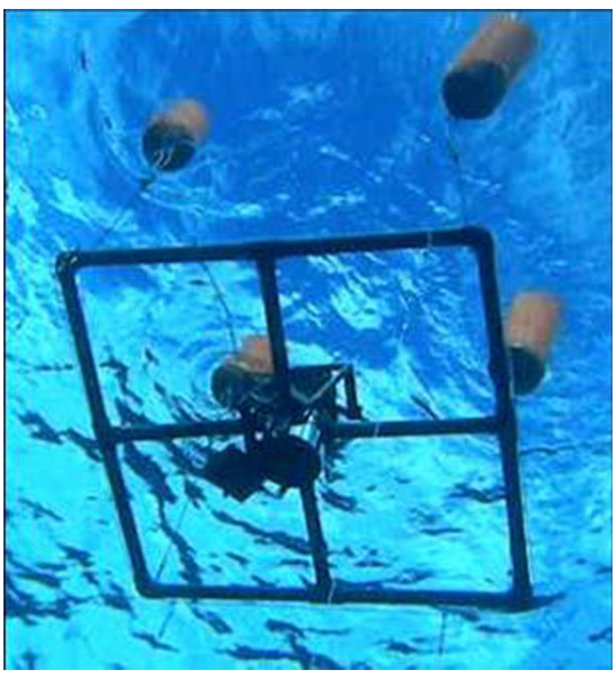

Figure 3. The platform was maintained at the sea surface by four buoys, and equipped with four branchlines at each corner, and a camcorder at its centre (tests with platforms).

Results

Dolphin interactions with platforms

During the 14 trials with platforms undertaken from 19 July 2010 to 18 August 2010, bottlenose dolphins were observed three times (numbered as 2, 4, and 7 in Table 1), while spinner dolphins were never observed near platforms.

During trial #2, a group of four bottlenose dolphins interacted with two platforms, one equipped with four and the other with three unprotected branchlines. When the platforms were hauled 1 h later, five fish were totally removed and one was partially damaged.

During the second interaction (trial #4), which occurred with a pod of 12 bottlenose dolphins, two experiments were undertaken. During the first experiment, two platforms were deployed, with four branchlines with the DEPREDs on each. They were hauled 1 h later and no depredation on fish was observed (trial #4A, Table 1). On the underwater video footage, dolphins were seen swimming around the protected branchlines maintained at a distance of ~1 m by the flapping streamers while they emitted clicks. For the second experiment, all DEPRED were removed from one platform and redeployed with three unprotected branchlines (trial #4B, Table 1). This platform was set at a distance of 20 m from the adjacent platform with protected branchlines. These two platforms were hauled 40 min later. Two out of three fish from the unprotected platform were depredated (Figure 4a), while depredation was not observed on the protected platform (trial #4B, Table 1).

Table 1. Summary of interactions between dolphins (bottlenose dolphins) and fish, for the first survey (with platforms)

		Without DEPRED		With DEPRED	
Experimental trial #	**Number of platforms set**	**Number of fish set**	**Number of fish depredated**	**Number of fish set**	**Number of fish depredated**
2	2	7	6	0	0
4A	2	0	0	8	0
4B	2	3	2	4	0
7	2	4	0	4	0

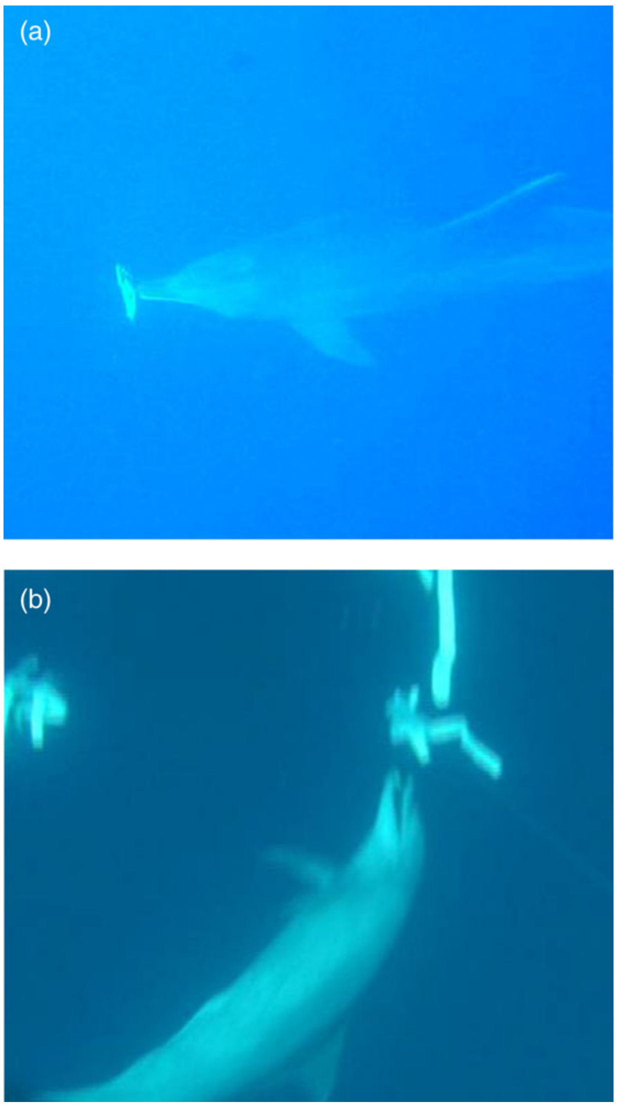

Figure 4. (a) A bottlenose dolphin attacking an unprotected fish. (b) A bottlenose dolphin attempting to attack a fish protected by the DEPRED.

The third interaction (trial #7) occurred between a pod of ten bottlenose dolphins and two platforms, one with four protected branchlines and a second with four unprotected branchlines. Both platforms were hauled 90 min later and no depredation was observed. Based on underwater video footages, only one dolphin was observed swimming around a protected branchline and attempting to bite one fish. The biting occurred on the only fish not fully protected by the DEPRED being suspended outside of the physical barrier designed by the weighted streamers (Figure 4b). It is worth noting that the expected deterrent effect of the startling streamers failed due to the absence of currents and turbulence.

This first set of observations provided preliminary but positive results for the efficacy of the DEPRED in a simulated situation, justifying a larger trial to assess its operational efficacy.

Dolphin interactions with an experimental longline

From 2 March 2011 to 1 June 2011, 20 longline experiments were carried out to quantify the operational efficacy of the DEPRED. Each longline was equipped with up to 40 unprotected and 40 protected branchlines. Bottlenose and spinner dolphins interacted with the longline on six and three experimental days, respectively. All the interactions with bottlenose dolphins occurred with the same pod and no co-occurrence of both species were observed during our trials.

For the nine longlines impacted by dolphin depredation, 339 protected and 330 unprotected SPF were set. Of these, 47 protected SPF (13.9%) and 103 unprotected ones (31.2%) were partially or fully damaged. The proportion of SPF depredated by bottlenose dolphins averaged 17.6% (ranging from 7.5 to 40%) for the protected branchlines and 31.8% (ranging from 10.3 to 67.5%) for the unprotected ones. The proportion of SPF depredated by spinner dolphins averaged 5% (ranging from 2.5 to 15%) for the protected branchlines and 29.9% (ranging from 17.9 to 65%) for the unprotected ones (Table 2).

The total DR for protected branchlines was ~13.9%, while the DR for unprotected fish reached 31.2%. On average, the protection rate was more than double for protected branchlines.

The Pearson's χ^2 test showed that the null hypothesis (i.e. no effect of DEPRED protection) is rejected for four trials, two involving bottlenose dolphins and two involving spinner dolphins (Table 3). For both species, a significant difference in DR between protected and unprotected branchlines was only observed for the first two trials. At the third trial of each series, the p-value is still close to the rejection threshold (p-value = 0.1 for bottlenose dolphins and 0.057 for spinner dolphins). For the rest of the bottlenose dolphin series, the difference between the two line configurations was not significant. It must be noted that a rather low p-value (0.1) is obtained again for trial #19 surprisingly corresponding to a larger proportion of attacked fish on protected branchlines. The trend of the Cramer's V value (estimated for the cumulated responses of depredation events on protected and unprotected branchlines) indicated a decline of the mitigation efficacy from the third longline set onwards for bottlenose dolphins, while this mitigation effect remained rather stable for spinner dolphins (Figure 5).

Table 2. Summary of interactions between dolphins (bottlenose and spinner dolphins) and fish on the longline for the two configurations (protected and non-protected).

Experimental trial #	Without DEPRED			With DEPRED			Species in interaction
	D	*I*	*D*/(*D*+*I*) (%)	*D*	*I*	*D*/(*D*+*I*) (%)	
4	19	19	50	6	34	15	*T. aduncus*
7	27	13	67.5	10	29	25.6	*T. aduncus*
12	9	29	23.7	3	37	7.5	*T. aduncus*
13	4	35	10.3	3	37	7.5	*T. aduncus*
16	7	32	17.9	4	36	10	*T. aduncus*
19	8	31	20.5	16	24	40	*T. aduncus*
14	13	7	65	3	17	15	*S. longirostris*
18	9	29	23.7	1	39	2.5	*S. longirostris*
20	7	32	17.9	1	39	2.5	*S. longirostris*
Total *T. aduncus*	74	159	31.8	42	197	17.6	
Total *S. longirostris*	29	68	29.9	5	95	5	

D, depredated fish; I, intact fish; *D*/(*D*+*I*), depredation ratio (in %).

Table 3. Pearson's χ^2 test values for individual experiments and Cramer's *V* value for cumulated results with respect to their chronology for each dolphin species.

Experimental trial #	By experimental trial χ^2	By experimental trial *p*-value	Cumulated Cramer's *V*	Species in interaction
4	9.41	0.0021	0.347	*T. aduncus*
7	12.26	0.00046	0.383	*T. aduncus*
12	2.78	0.1	0.329	*T. aduncus*
13	0.0012	0.97	0.27	*T. aduncus*
16	0.48	0.49	0.24	*T. aduncus*
19	2.68	0.1	0.16	*T. aduncus*
14	8.44	0.0037	0.459	*S. longirostris*
18	6.04	0.01	0.357	*S. longirostris*
20	3.62	0.057	0.45	*S. longirostris*

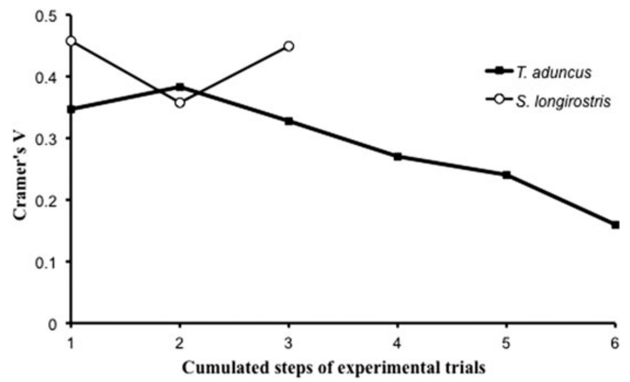

Figure 5. Trend of the Cramer's *V* calculated for cumulated steps of experimental trials between experimental longlines and dolphin species (black square, *T. aduncus*; white circle, *S. longirostris*).

Discussion

Few depredation mitigation devices for pelagic longlining have been designed and tested so far; they concerned with either acoustic (McPherson *et al.*, 2008) or physical protection (Hamer *et al.*, 2012; Rabearisoa *et al.*, 2012). Some acoustic tests with dolphin dissuasive devices and dolphin interactive dissuader are being tested by Japanese pelagic longliners in the Indian Ocean (T. Nishida, pers. comm.). As far as we know, very few results of physical protection devices tested during commercial fishing operations have been published (Hamer *et al.*, 2012; Hamer and Childerhouse, 2012; Rabearisoa *et al.*, 2012). This study is the follow-up to previous experiments on toothed whale depredation using mitigation devices named "spider" and "net sleeve" (Rabearisoa *et al.*, 2012). Whereas those devices were merely designed as physical protection systems, the DEPRED adds a potential dissuasive effect in the shape of several flapping streamers designed to create a protected area between odontocetes and their target, the captured fish.

Our results based on the quantification of the simulated and operational efficacy of the DEPRED and on observations of underwater video footages showed a positive depredation mitigation effect of the device at least at the beginning of observations. Dolphins interacting for the first time with DEPRED did not damage the SPF, while they depredated unprotected ones. Experimental longline trials carried out 8 months later with the same group of dolphins confirmed a similar behaviour at a larger scale and highlighted an obvious depredation mitigation effect of the DEPRED. For almost all trials, depredation was two times higher on unprotected branchlines than on protected ones. We hypothesize that the mechanism leading to this result is linked to the avoidance by dolphins of physical injuries or risk of entanglement due to both the protecting and flapping streamers diverting their depredation attack towards unprotected fish. Overall, the design of the DEPRED would make an approach to the potential prey more difficult for the reasons presented above and would deter toothed whales from engaging in depredation.

The operational efficacy of the DEPRED was greater during the first two interactions between dolphins and the longline. For bottlenose dolphins, the depredation mitigation effect decreased from the third interaction event, while it remained rather stable for spinner dolphins across the three interaction events that were observed. After a period of exposure to the deterrent effect of flapping and/or protecting streamers, bottlenose dolphins may stop responding to this stimulus. This behaviour, known as habituation (Rose and Rankin, 2001), confirms the learning ability of marine mammals to ignore a stimulus when its harmfulness is an illusion. Such ability might explain their fast habituation to new DMMs, such as acoustic ones, in which the acoustic deterrent effect turns into "a dinner bell effect" after few exposures (Jefferson and Curry, 1995;

Mooney *et al.*, 2009). Nonetheless, the habituation we observed in coastal waters might be less of an issue for longline fisheries operating in the pelagic realm, as interactions may occur with both highly mobile and non-resident pods. However, our knowledge about the population ecology of the toothed whales species involved in depredation (i.e. short-finned pilot whales and false killer whales) is still poor, especially in our study area. We cannot exclude the possibility that individuals interacting with fishing vessels may also belong to a few groups regularly involved in depredation events. Consequently, a regular exposure to the DEPRED may induce habituation behaviour that could be similar to the one observed during our trials. This question will be carefully investigated when our devices are tested in the open ocean and we are aware that a large dataset and a long-term study (involving methodology to individually identify depredators) will be necessary to address this particular issue.

No interaction with sharks was observed during the surveys. Therefore, the mitigation skills of the DEPRED could not be assessed for those predators. However, sharks can detect their prey through changes of the ambient electrical field (Kalmijn, 1971) and the material currently used to design our prototype does not have this repelling property. Nevertheless, the flapping streamers might discourage them from approaching the fishing gear. Studies based on the reduction in shark interactions with pelagic longlines provide some promising new strategies for shark avoidance, including electropositive metals or electrical shark avoidance devices (Gilman *et al.*, 2008). The next design of the DEPRED may therefore include some metals to strengthen its deterrent effect on sharks (McCutcheon and Kajiura, 2013).

The next stage of trials of our depredation mitigation device will be conducted in the open ocean, during commercial fishing operations. Pelagic longliners operating in the southwest Indian Ocean set on average between 400 and 1500 branchlines during each fishing operation. The final prototype of the DEPRED is aimed to be deployed on all branchlines during commercial fishing operations. Several passive acoustic reflectors will be set at the extremity of the flapping streamers. Those hollow balls are intended to increase the buoyancy of those streamers and to modify the acoustic signal of the caught fish. Indeed, they will provide an additional acoustic barrier between the echolocating toothed whales and the captured fish. To make this acceptable to the operators, various technical adaptations must be developed. The DEPRED is aimed at being locked up in a case, and that case must be easily set at the top of the branchline. The device must be mechanically released when the fish is biting the bait (Hamer *et al.*, 2012; Rabearisoa *et al.*, 2012). This triggering system differs from those developed for depredation mitigation devices such as the "cachalotera", deployed on demersal longlines that is triggered by gravity and the simple friction of the water on the device during the hauling operation (Moreno *et al.*, 2008). Additionally, the potential effect of the device deployment on the catchability of the target resources is paramount for acceptance by fishers. This precondition could not be verified during our trials, but we observed that the previous deployment of "spider" and "sock" devices did not affect the catch per unit effort (cpue) of the longline by comparison to control experiments (Rabearisoa *et al.*, 2012).

Depredation has potential impacts on the ecology and conservation of odontocetes and can severely affect the economic sustainability of pelagic longline fleets when DRs are too high. When not estimated, depredation also leads to underestimation of the fishing mortality of target species, with consequences for stock assessment. The ecosystem approach to fisheries states that fisheries impacts on biodiversity in general, and on threatened or endangered species in particular, should be minimized and therefore, research on mitigation measures is strongly recommended (Garcia *et al.*, 2003). Depredation research is perfectly aligned with this objective, as it is designed to overcome both economic and conservation issues in fisheries. However, this remains a poorly studied topic. We believe that all initiatives taken in this direction need to be communicated and published. Indeed, those results need to be consolidated by expanding the trials in commercial fishing operations to assess more accurately the efficacy of the DEPRED. This study provides valuable insights into depredation reduction on pelagic longlines using an improved design of a deterring device. However, we are aware that a great challenge still awaits us in designing the next DEPRED prototypes, since we may have to deal with toothed whale habituation towards our devices. But if proven successful, the field of application will be huge as interactions between toothed whales and pelagic longline fisheries occur worldwide, with some concern for the conservation of several toothed whale populations.

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