Report of a workshop on the analysis of existing data from prawn trawl nets with Turtle Excluder Device (TED) and without TED (non-TED) in the Western Indian Ocean

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Background

With the support of the Western Indian Ocean Marine Science Association (WIOMSA), a multi-country research project into assessment and mitigation of marine megafauna bycatch in Western Indian Ocean fisheries (BYCAM) commenced in 2015. The project is focussed on coastal gill-net and longline fisheries, and (semi) industrial prawn trawl fisheries. The latter component is particularly dealing with the investigation of Turtle Excluder Devices (TEDs) so as to assist with implementation of TEDs in the Mozambican prawn trawl fishery.Before commencing TED trials in Mozambique (planned for early 2016), two BYCAM activities were undertaken to provide information on existing experiences with TEDs in the WIO region: 1) a fact-finding visit to Madagascar (Appendix 1), where TEDs have been implemented since 2005 and 2) a workshop analysis of data to compare catches from TED and non-TED trawls recently undertaken in the region; the latter activity forms the basis for this report.

Introduction

Prawn trawling is known to produce large amounts of bycatch (Kelleher 2005), and prawn trawl fisheries in the southwest Indian Ocean (SWIO) are also implicated in this (Fennessy et al 2004, Fennessy and Everett 2015a, 2015b). Bycatches of turtles and elasmobranchs are of particular concern owing to the vulnerabilities of these species, reflected in the appearance of many of them on the IUCN Red List of Threatened Species. Estimates of trawled catches of turtles from the region are not robust; Wallace et al (2010) derived an estimate for the whole western Indian Ocean (including the Arabian Gulf and the Red Sea) of around 10 500 turtles, but included virtually no records for Kenya, Tanzania and Madagascar. A recent analysis used a combination of historical and current catch rates together with fleet effort to derive annual figures of between 1 100 and 2 900 trawled turtles per year for the SWIO (Table 1). Even if the lower estimate of trawled turtle catches is more accurate, it is apparent that 1) considerable numbers are trawled in the SWIO, 2) the majority are trawled in Mozambique and 3) TEDs appear to be effective in reducing turtle catches by trawlers.

Table 1: Current annual trawled catches of turtles from the SW Indian Ocean (after Mellet 2015)

Country	**Annual turtle catches**	**Comment**
Kenya	59 – 167	This figure is subsequent to TED implementation in 2001; 500 – 1 000 turtles p.a. were caught in the 1990s when effort was high (Wamukoya and Mbendo 1995, reported in Wamukoya and Salm 1997). Since 2012 max number of operating trawlers is three.
Tanzania	54 – 76	Fishery currently closed, only experimental trawling allowed. However during stock assessment surveys in 2008 and 2015, several sea turtles were caught. From prawn trawler reports, there are areas in which turtles are regularly caught - specifically in Bagamoyo (Saadani) and Kisiju (Buyuni)
Mozambique	1 008 – 2 394	A more recent estimate, based on skipper interviews, of 1 735 ± 1 235 turtles p.a. caught on the Sofala Bank in central Mozambique is available in Brito (2012).
Madagascar	2 – 184	The lower figure is based on post-TED implementation in 2005, the higher figure is pre-TED. Both are underestimates, being based only on reported numbers of turtles per observer trip in 2004 and 2005 (Razafindrainabe 2010) i.e. not scaled up using fleet effort (STF pers. obs).
South Africa	20 – 50	Figures based on turtle catches prior to 2004; virtually no shallow-water trawling has occurred since 2007.

Prawn trawlers also catch considerable amounts of elasmobranchs, but even fewer figures are available from the SWIO for these organisms. From 1989 to 1992, Fennessy (1994) analysed the elasmobranch bycatch of the South African shallow-water prawn trawl fishery and estimated that 44 600 elasmobranchs were caught in this fishery during the four-year study period, with high levels of mortality.

The first effort to introduce TEDs in the region took place in Kenya (Wamukoya and Salm 1997), with legislation requiring their use in Kenya being introduced in 2001. Compliance was poor however, until the formalisation of the prawn fishery management plan in 2010, when regular use of TEDs commenced. Since 2005, TEDs have been in use in the industrial fleet in Madagascar, with good compliance (Fennessy et al. 2008, Appendix 1), while the Tanzanian prawn management plan makes reference to their use in that country. Since the fishery is closed, TED implementation will start once the fishery is opened.. In South Africa, there is no requirement for TED use. There has been limited formal testing of TEDs in Mozambique, in the form of a Nordmöre grid (Fennessy and Isaksen 2007), and informal TED trials have been undertaken by some of the fishing companies (S. Sitoe, ADNAP, pers. comm.). The US-based National Oceanic and Atmospheric Administration has also conducted a demonstration TED workshop (A. Brito, IIP, pers. comm.). However, although TEDs have been compulsory in terms of legislation since 2004, they are not in use.

Mozambique supports one of the largest prawn trawling fisheries in the WIO region, and, in an effort to assist with implementation of TED use in that country, analyses were undertaken of data recently generated by the South West Indian Ocean Fisheries Project (SWIOFP), one of the objectives of which was to examine differences in TED vs non-TED catches in the WIO region.

Methods

Data availability

As part of SWIOFP, shallow-water prawn surveys were undertaken in Kenya and Tanzania in 2011 to determine, amongst others, species composition and distribution of prioritized crustacean species. These surveys presented opportunities to test the effectiveness of TEDs in these two countries. The surveys occurred in the North East Monsoon (NEM) and South East Monsoon (SEM), from 22nd January to 4th February and May 21st to June 4th in Malindi-Ungwana Bay in Kenya, while the Tanzanian surveys occurred from February 9th to 23rd and June 13th to 25th in three fishing areas: Zone 1 - Bagamoyo/Saadani; Zone 2 - Rufiji Delta; Zone 3 - Jaja/Kilwa. The prawn trawler MF Vega was used for the surveys, with LOA 24.96m, 146 GRT, width 7.20 m and a draught of 2.5 m, an engine capacity of 496 HP and fitted with two outrigger trawl nets. The length of each net was 44.3m including wings, net body and cod-end. The wings were 19.1 m long (45 mm mesh), the net body was 19.1 m long (70.4 mm mesh) and the codend was 6.1 m long (45 mm mesh). Both nets had a head rope of 26.4 m, a foot rope of 25.4 m and a restraining chain of 28 m between the two doors which were 2 m long by 1 m high, and weighed about 250 kg each. The net mouth had an estimated height of 3 m. One net was fitted with an aluminium TED, which was oval with a height of 125 cm and a width of 108 cm, and with 8 parallel vertical bars about 14 cm apart (Figure 1). The TED was inclined at an angle of about 70-80 degrees, and was mounted at the front of the codend, with an escape opening in the top panel; the opening was covered with a flap of netting. The vessel's crew remained the same for all surveys, with the exception of the addition of a fishing master in Tanzania who assisted with trawling operations; the scientific crew were comprised of staff from KMFRI and TAFIRI for the surveys in Kenya and Tanzania respectively.

Trawls were of one hour duration if the sea bed condition allowed; time, GPS position and depth at the start (trawl on bottom) and end of the trawl (trawl haul commenced) were recorded, as well as the average trawl speed in the case of Tanzania; trawl speed in Kenya was subsequently estimated from a combination of trawl duration and distance trawled. Physico-chemical parameters were also measured, but were not considered in the analyses (see Data analysis). Catches from TED and non-TED trawls were kept separate; small catches were sampled in their entirety while larger catches were subsampled and scaled up to determine total catch, using a raising factor based on the weight of the subsample relative to the total catch weight (see Stobutzki et al., 2001; Tonks et al., 2008). Numbers and weights of individual taxa were enumerated for each trawl. Greater details on the sampling and data collection are available in Kimani et al. (2012a, 2012b) and Mwakosya et al. (2012).

Also available was a set of TED vs non-TED trawl catch records from Madagascar which were provided by CEDP. These catch records were from an industrial trawling company in Mahajunga. The company conducted trials on one vessel during commercial operations on the west coast from 6th to 25th of November 2013. The vessel had four nets (two per outrigger), two with TEDs and two without. Catch weights of prawns and total retained fish on a per-trawl basis were provided for the combined pairs of TED and non-TED nets.

Plate 1: The TED fitted in a trawl net used on the prawn trawl surveys in Kenya and Tanzania in 2011.

Data analysis

For the Kenyan and Tanzanian TED vs non-TED data analysis, the prawns *Penaeus indicus*, *Metapenaeus monoceros*, *P. japonicus*, *P. monodon* and *P. semisulcatus* were aggregated as Target catch, while all other taxa (mainly teleosts) were considered as Bycatch. Nominal catch data were standardized to total kg and number of individuals of Target and Bycatch organisms per trawl hour. The question we were attempting to answer was: Is there a difference between TED and non-TED catch rates of Target and Bycatch? Examination of comparative TED/non-TED mean catch rates per country and season (Table 2, Results) suggested considerable differences, and, although not tested, it was probable that the data were not normally distributed. Generalized Linear Models (GLMs) were therefore used to compare comparative TED/non-TED catch rates and, subsequently, to investigate potential factors which could influence TED functioning.

After consideration, we decided that three factors could be explanatory/influential for catch rates with respect to this second question, namely country, trawl speed and size of catch. While country is not obviously an influential factor, since the vessel, gear and methodology were the same for both countries, initial perusal of the data suggested some differences (see Results). Trawl speed and catch size are potentially influential as they can affect the functioning of TEDs (Broadhurst 2000) e.g.

increased trawl speed may increase the rate at which organisms pass through the TED and into the codend before they have a chance to escape through the TED opening, while catch build-up in the codend may affect trawl gear efficiency and may also affect the passage of organisms though the TED via altered water flow in the net. Catch sizes were categorized as Large (> 100 kg) and Small (< 100 kg). All other factors, such as season (NEM/SEM), depth, salinity, etc. were either deemed non-influential on TED vs non-TED catch rates i.e. their influence was the same for both trawl types, or were considered to be correlates of the catch size factor.

The variability in the trawl catch rates was explored using generalised linear models (function GLM) in the freely available statistical software package R version 2.15.2 (R Development Core Team 2012). Several approaches are available to model fisheries' catch-rate data (Maunder and Punt 2004). The gamma model was selected for the Bycatch catch rates as no zero catches were recorded, and the delta method was selected for the Target catch rates because some trawls had no catches of prawns (i.e. zero Target catch). The delta method, which has been described extensively by Lo et al. (1992) and Maunder and Punt (2004), is one of the most widely applied in fisheries science. The method involves fitting two submodels to the data (Lo et al. 1992). In the first submodel, the probability of obtaining a non-zero catch (of Target prawns in this study) is modelled, assuming a binomial error distribution. In the second submodel, only the positive catch rates (i.e. from trawls with Target prawns) are modelled, assuming a gamma error distribution. The gamma error distribution with a log link was used, because residuals were then randomly distributed, and this distribution fitted the data best, based on the Akaike Information Criterion (AIC). The final delta model is then the product of the probability of capture (binomial submodel) and catch rate of trawls with non-zero Target catches (gamma submodel). Catch rates of Bycatch and Target, separately, were the response variables (continuous), while country, trawl speed and catch size were considered as explanatory variables. The following trawls were eliminated before analysis because they were anomalous: One trawl from Kenya that had no catch in the non-TED net and only 1 kg in the TED net; one trawl from Kenya that had a starting depth greater than 45 m; three trawls from Kenya with a trawl speed of less than 2 knots; one trawl from Tanzania with a trawl speed of greater than 3 knots.

For the commercial trawl data from Madagascar, the number of trawls (165) was sufficiently high to overcome the apparent skewness of the data (non-normal), so paired two-sample t-tests for differences in means were run in Microsoft Excel.

Results

In total, 30 Kenyan trawls (15 NEM and 15 SEM) and 68 Tanzanian trawls (31 NEM and 37 SEM) were undertaken using a TED (Table 2); the lower number of trawls in Kenya was because several trawls were undertaken using a single net in deeper water (> 50m), precluding a comparison of TED vs non-TED catches in those trawls. No turtles were caught in the surveys, and elasmobranch catches were too infrequent (18 positive trawls out of 98) and, except for the Kenyan SEM survey, were too small to test for TED/non-TED differences (Table 3). The increased numbers on the Kenyan SEM survey may have been an unintended artefact of the sub-sampling process, but there is some suggestion that the TED trawls excluded more elasmobranchs than non-TED trawls.

There were marked contrasts between mean catch rates of Target and Bycatch (in weight and/or in number), as a function of country (Kenya and Tanzania), and/or season (NEM and SEM; Table 2). However, the potential role of season in TED effectiveness was considered to be mediated via catch size, so season was ignored in the GLMs.

Table 2: Comparative mean catch rates (per hour) of Target (prawns) and Bycatch (all other organisms) in TED and non-TED trawls on SWIOFP shallow-water prawn surveys in January-February (NEM) and May-June (SEM) 2011. Number of trawls in parentheses.

	Target no.		Target kg		Bycatch no.		Bycatch kg	
	TED	Non-TED	TED	Non-TED	TED	Non-TED	TED	Non-TED
Kenya								
NEM (15)	136	315	4	4	665	912	32	72
SEM (15)	675	749	12	12	1 598	1 070	64	114
Tanzania								
NEM (30)	703	851	15	16	1 787	1 565	74	68
SEM (37)	798	803	13	13	3 003	3 546	95	103

Table 3: Elasmobranch catches in TED and non-TED trawls on SWIOFP shallow-water prawn surveys in January-February (NEM) and May-June (SEM) 2011.

	Kenya NEM		Kenya SEM		Tanzania NEM		Tanzania SEM	
	TED	Non-TED	TED	Non-TED	TED	Non-TED	TED	Non-TED
No. of elasmobranchs	0	5	17	44	4	3	3	3

The GLMs of the combined data considering only TED/non-TED as a factor indicated that TED trawls had slightly lower Bycatch rates (both no. and kg), while Target catch rates from TED trawls were slightly lower by number but higher by weight (Figure 2). This suggests that the TEDs were not working very effectively i.e. bycatch was reduced only slightly.

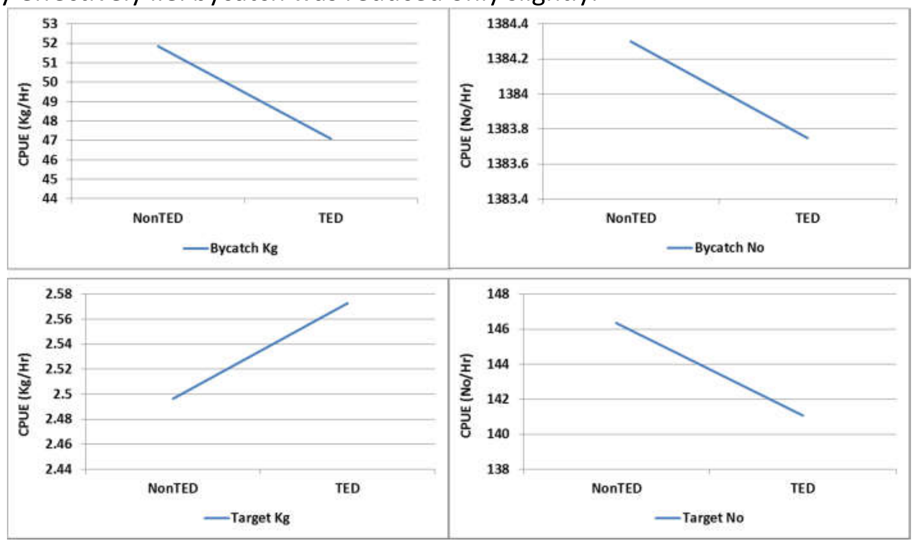


Figure 1: Plots of Generalised Linear Models showing the effect of TEDs on standardized catch rates from SWIOFP shallow-water prawn trawls undertaken in Kenya and Tanzania in 2011. Data for the two countries were combined. Differences in catch rates were extremely significant ($p < 0.001$) except for Target kg (very significant; $p < 0.01$).

Subsequent GLMs used to explore the factors which could potentially influence the effectiveness of TEDs showed that Bycatch rates by number from TED and non-TED trawls in Tanzania were substantially higher than in Kenya (Figure 3, Table 4). To be expected, catch size substantially affected Bycatch catch rates (by number and weight). Trawl speed affected non-TED catch rates of Bycatch numbers, with higher catch rates at slower speeds. Catch rates of Target prawns were substantially higher from non-TED trawls in Tanzania, but, although significant, there was not much difference between non-TED and TED Target catch rates in Kenya. Catch size substantially affected Bycatch rates (by number and weight) on non-TED trawls. While there appeared to be higher Target catch rates at slower speeds from non-TED trawls, the probability was only significant for numbers of Target prawns from TED trawls (Table 4). The relative contribution these three factors make towards the total percentage deviance explained (Table 4) also indicate that Country and Catch size are the most influential, and the relatively high total percentages for Bycatch (number and weight) and for TED Target (by number., Gamma model) suggest the models provide a reasonable explanation for observed variability in catch rates of these components of the catch.

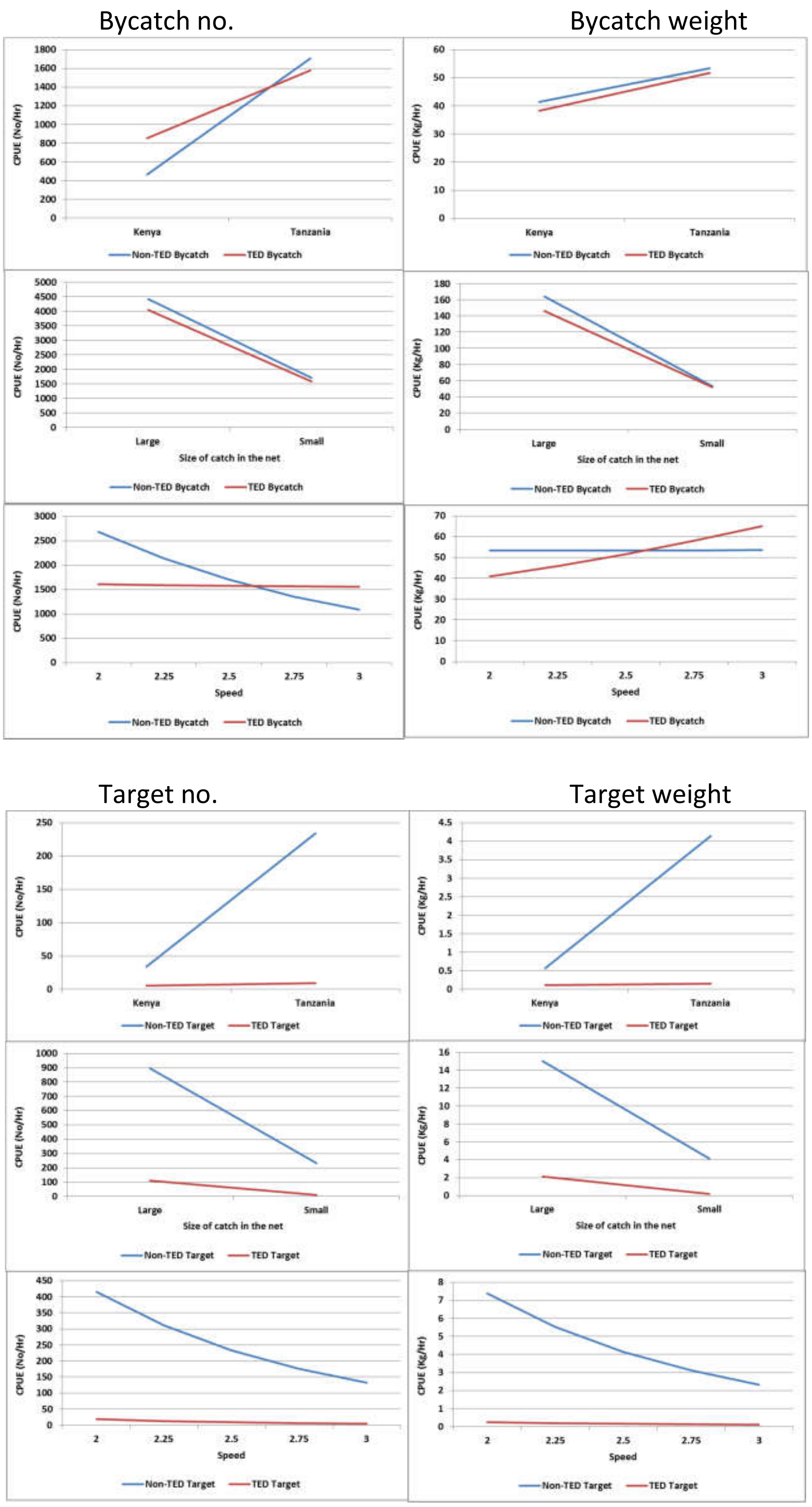


Figure 2: Plots of Generalised Linear Models showing the effect of Country, Catch size and Trawl speed on TED and non-Ted standardized Bycatch and Target catch rates from SWIOFP shallow-water prawn trawls undertaken in Kenya and Tanzania in 2011. Data for the two countries were combined.

Table 4: Significance levels obtained from Generalised Linear Models conducted on catch rate data from SWIOFP shallow-water prawn trawls undertaken in Kenya and Tanzania in 2011. Data for the two countries were combined. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, NS not significant. The percentage of deviance explained by each factor is indicated in parentheses.

	Bycatch (no.)		Bycatch (kg)		Target (no.)				Target (kg)			
	TED	Non-TED	TED	Non-TED	TED		Non-TED		TED		Non-TED	
Model	Gamma	Gamma	Gamma	Gamma	Binomial	Gamma	Binomial	Gamma	Binomial	Gamma	Binomial	Gamma
Country	*** (15)	*** (22)	*** (10)	*** (0)	NS (3)	*** (32)	* (14)	*** (0)	NS (3)	* (1)	* (14)	** (1)
Speed	NS (2)	* (3)	NS (0)	NS (0)	NS (4)	* (19)	NS (2)	NS (3)	NS (4)	NS (3)	NS (2)	NS (3)
Catch size	*** (24)	*** (26)	*** (35)	*** (55)	NS (5)	** (3)	NS (0)	*** (14)	NS (5)	*** (10)	NS (0)	*** (14)
% of total deviance explained by model	41	51	45	55	12	54	16	17	12	14	16	18

There was no obvious reason why Country should have been influential, since the same vessel, gear and methodology were used for both Kenya and Tanzania. It is possible that the disparate number of trawls between the two countries may have accounted for this; the markedly lower catch rates in the NEM season in Kenya (Table 2) may also have contributed, or there may have been some other unknown factor(s) on their respective surveys. To overcome the possible confounding role of Country when assessing the effects of TEDs on catches, separate GLMs were conducted on the data sets from the two countries. These indicate differential effects of the TEDs on Bycatch and Target catch rates in these two countries.

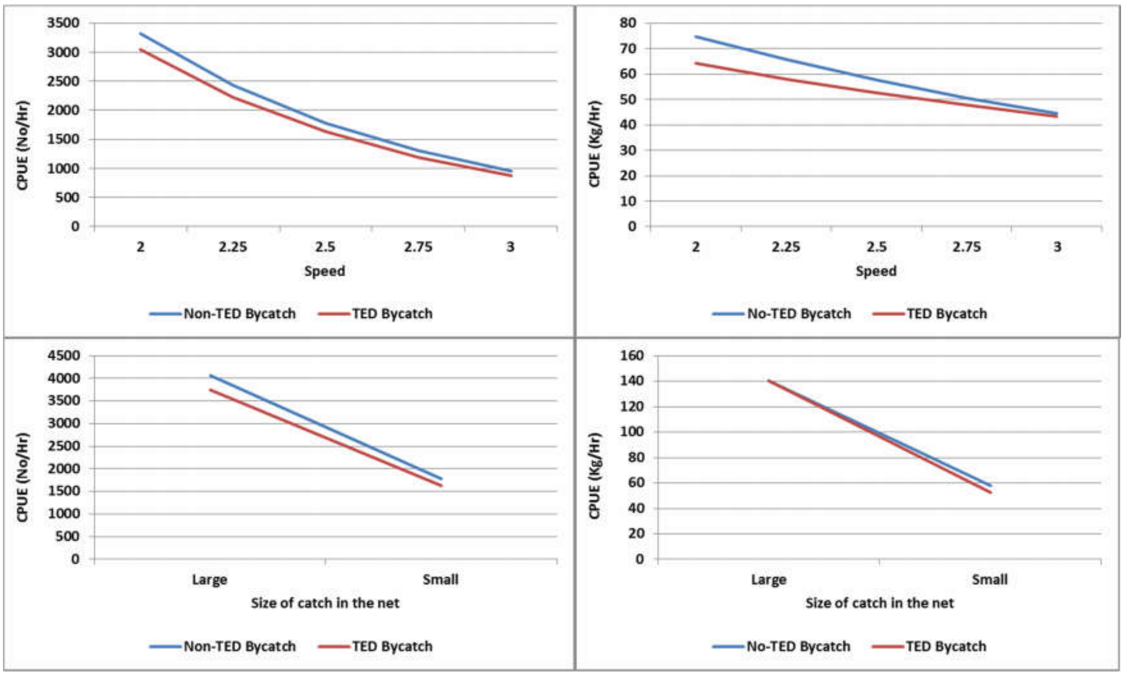
In Tanzania, trawl speed and particularly catch size influenced catch rates, but there was little difference between Bycatch rates on TED and non-TED trawls, whereas Target catch rates in non-TED trawls were considerably higher than in TED trawls at slower trawl speeds and when catches were large (Figure 4a, Table 5). Thus, the TED did not reduce Bycatch, but reduced Target catches. In Kenya, Target catch rates in TED trawls were considerably higher than in non-TED trawls when catches were large, and regardless of trawl speed; Bycatch catch rates from TED trawls were similar to non-TED trawls at slower speeds, and were greater when trawl speeds increased; TED trawl Bycatch rates by number were higher than non-TED rates when catches were large but Bycatch rates by weight were similar in TED and non-TED trawls in both large and small catches (Figure 4b, Table 5). Thus the TEDs increased Target catches except when catches were small, but also increased Bycatch particularly at faster speeds and (by number) when catches were large.

Table 5: Significance levels obtained from Generalised Linear Models conducted on catch rate data from SWIOFP shallow-water prawn trawls undertaken in Kenya and Tanzania in 2011. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

	Bycatch (no.)		Bycatch (kg)		Target (no.)				Target (kg)			
	TED	Non-TED	TED	Non-TED	TED		Non-TED		TED		Non-TED	
Model	**Gamma**	**Gamma**	**Gamma**	**Gamma**	**Binomial**	**Gamma**	**Binomial**	**Gamma**	**Binomial**	**Gamma**	**Binomial**	**Gamma**
						Tanzania						
Speed	*	*				*	*				*	
Catch size	***	***	***	***		***	*	***		***	*	***
						Kenya						
Speed							*				*	
Catch size	***	***	***	***		*	*	**			*	**

Tanzania

Bycatch no. Bycatch weight



Target no. Target weight

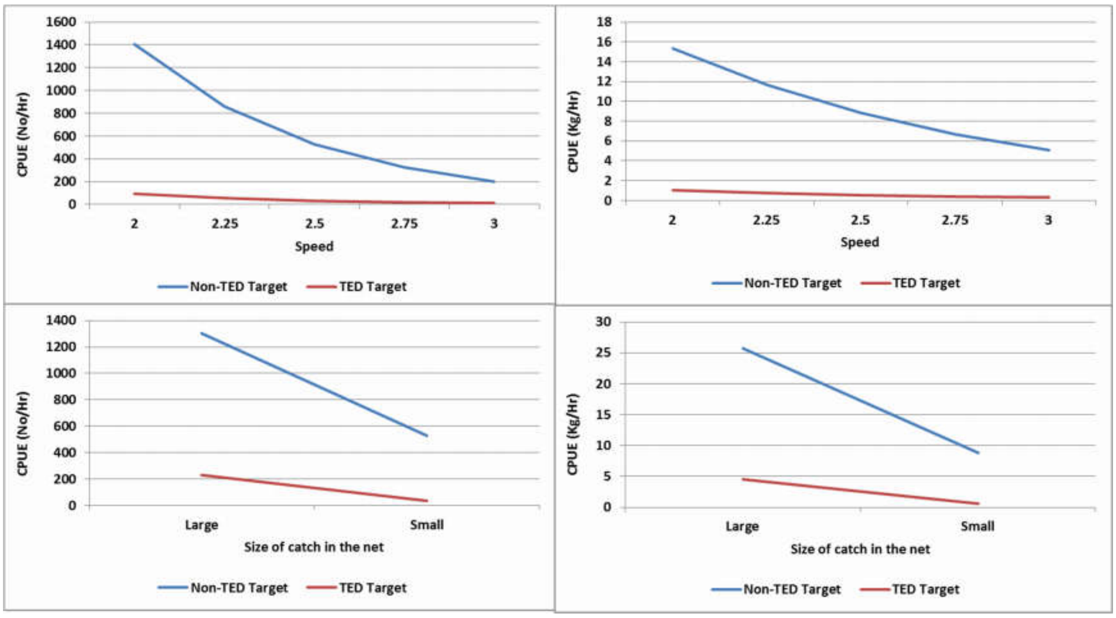
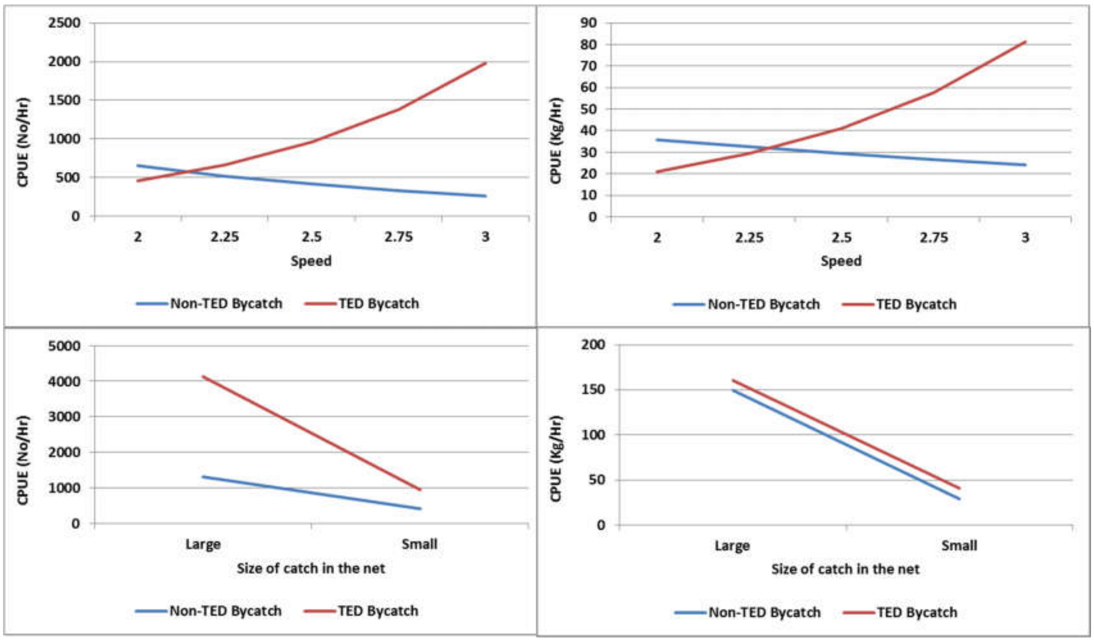


Figure 4a: Plots of Generalised Linear Models showing the effect of Catch size and Trawl speed on TED and non-TED standardized Bycatch and Target catch rates from SWIOFP shallow-water prawn trawls undertaken in Tanzania in 2011.

Kenya

Bycatch no. Bycatch weight



Target no. Target weight

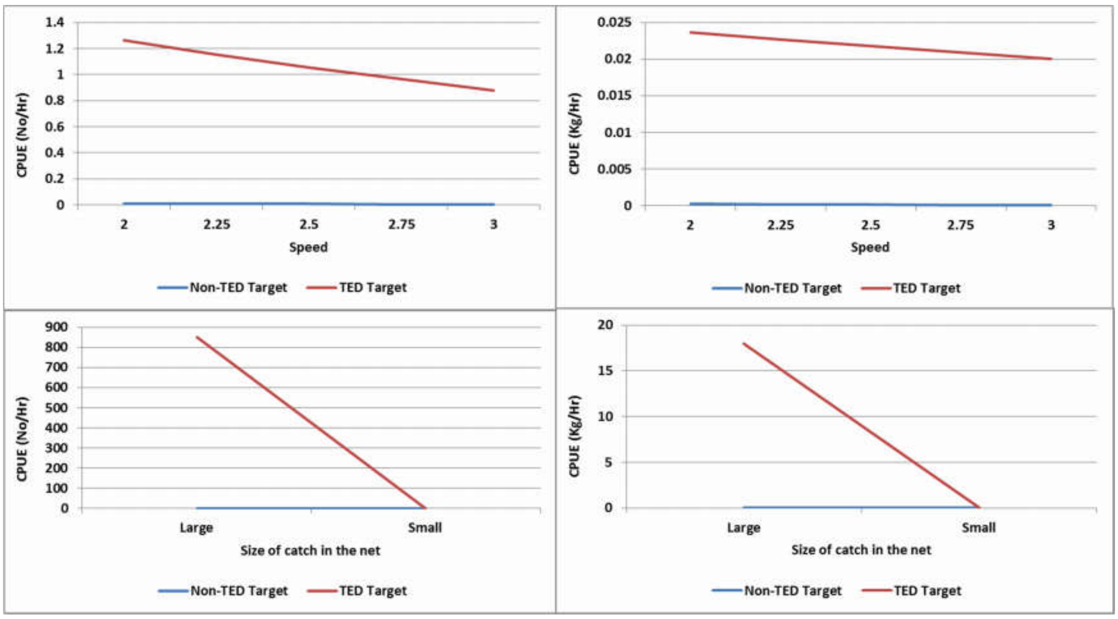


Figure 4b: Plots of Generalised Linear Models showing the effect of Catch size and Trawl speed on TED and non-TED standardized Bycatch and Target catch rates from SWIOFP shallow-water prawn trawls undertaken in Kenya in 2011.

The paired two-sample t-tests on the commercial trawl data from Madagascar showed that the trawls with TEDs caught considerably fewer prawns and fish than non-TED trawls (Table 6). Two turtles were caught in this period, in a net without a TED.

Table 6: Results of paired two-sample t-tests for differences in means of catches from 165 commercial trawls from western Madagascar in November 2013. Data provided by a Madagascan trawling company.

	Prawns (kg)		**Retained fish (10kg boxes)**	
	TED	**Non-TED**	**TED**	**Non-TED**
Mean catch	10.85	16.21	1.62	2.81
SD	8.41	10.63	2.35	3.93
t	-10.7		-6.91	
p	< 0.0001		< 0.0001	

Discussion

No turtles were caught in the Kenyan and Tanzanian surveys, and elasmobranch catches were insufficient to test the effectiveness of the TEDs, although there was some indication that the TED trawl caught fewer of these organisms than the non-TED trawl.

Nominal catch rate results from the SWIOFP surveys (Table 2) suggest that, in both Kenya and Tanzania, catch rates of numbers of prawns in TED trawls were lower than in non-TED trawls, particularly on the first survey in each country, but the prawn catch rates by weight in TED and non-TED trawls were very similar in each case. In Kenya, bycatch catch rates by weight and number in TED trawls were considerably lower than in non-TED trawls, except on the second survey when bycatch rates by number in TED trawls were greater than in non-TED trawls. In Tanzania, bycatch rates by weight and number in TED trawls were similar to those in non-TED trawls, except on the second survey when bycatch rates by number in TED trawls were considerably lower than in non-TED trawls. The nominal results thus present some conflicting findings. The initial GLM models, incorporating only the presence or absence of a TED as an explanatory factor for both countries combined, showed that the TED reduced bycatch only slightly, and that prawn catch rates were increased slightly by weight and decreased slightly by number in TED trawls. These overall results suggest that the TED was not functioning particularly well on the surveys.

Subsequent GLM models were used to investigate potential factors which may have affected TED functioning. These showed that trawl bycatch rates were considerably higher in Tanzania, and that TED trawls in Kenya had higher bycatch rates than non-TED trawls; conversely, non-TED trawls in Tanzania had slightly higher bycatch rates than TED trawls. However, target catch rates in non-TED trawls in Tanzania were much higher than in non-TED trawls in Kenya, and were also much higher than in TED trawls in Tanzania. Target catch rates on non-TED trawls in Kenya were slightly higher than in TED trawls. The effect of the TED on bycatch rates was not particularly affected by catch size, although non-TED catch rates were slightly higher than TED catch rates when catches were large; however, non-TED catch rates of target prawns were higher than TED catch rates for both large and small catches, and particularly when catches were large. Trawl speed showed variable effects on TED function with respect to bycatch catch rates (Figure 3), but, for target prawns, non-TED catch rates were greater than TED catch rates regardless of speed, and were particularly greater at slower speeds.

When catch rates were examined on a per-country basis, it was broadly observed that, in Tanzania, both bycatch and target catch rates were higher in TED trawls, and this was particularly the case for target catch rates at slower speeds and when catches were large (Figure 4a). In Kenya, the opposite was broadly seen: TED catch rates (target and bycatch) were generally higher than non-TED catch rates, although this was less marked when catches were small (Figure 4b).

Overall, it may be concluded that the TED used in the Kenyan and Tanzanian surveys was not functioning effectively , as bycatch rates were not much reduced (in Tanzania) and were increased relative to non-TED catch rates (in Kenya). Prawn catch rates were reduced in Tanzanian TED trawls but were increased slightly in Kenyan TED trawls.

The Madagascan information was not verified independently, but suggests that the TEDs used in that survey are also not functioning correctly, as prawn catches were considerably reduced in the TED trawls. It may be expected that retained bycatch is reduced in TED trawls relative to non-TED trawls owing to the release of larger fishes by the TEDs.

It was not the intention of the workshop to compare TED effectiveness between Kenya and Tanzania – the data were only separated in order to try and understand if the TED was working effectively and what could be affecting it. Unfortunately the observed differences cannot be explained with the information available. One possible factor is that the distances trawled in Tanzania were derived from haul duration and estimated speed, whereas in Kenya they were derived from haul duration and grid reference positions at the beginning and end of the trawls. Inaccuracies in trawl speed estimation may have affected catch rate calculation, with consequences for the assessment of the relative performance of TED versus non-TED trawls. Other uncertainties exist in the consistency of hauling up of trawls without reducing forward motion of the trawler – a “haul-back delay” can cause the catch to wash forward in the trawl resulting in losses via the TED (Watson 1989), or in the amount of time the net is on the surface after hauling, which may cause loss of catch. It also appears there was no comparison of the catches by the two nets before the TED was installed i.e. to account for possible pre-existing biases in catch efficiency.

Correctly rigged, TEDs should reduce bycatch (of some fishes, not only turtles and elasmobranchs) and should not reduce prawn catches substantially – prawn catches may even be increased relative to non-TED catches owing to increased gear efficiency (Isaksen 1992, Brewer et al. 1998, Broadhurst 2000, Fennessy and Isaksen 2007). It is not apparent to what extent the rigging of the TED used on the MF Vega in the SWIOFP surveys is checked and adjusted, but this is something which needs to be undertaken frequently, as the trawl nets change over time because of stretching, resulting in changes to the TED angle (FAO 2007).

For the testing of TEDs in Mozambique, it is emphasized that the potentially influential factors which could compromise analysis of results, as described above, be neutralized as much as possible. Testing procedures and conditions must be standardized to avoid bias, while providing adequate replication to enable rigorous statistical analysis to satisfy both managers and the industry as to whether the TEDs are functioning correctly. This will require skills transfer from a fishing gear specialist, co-operation from industry, well-trained observers and capable scientists.

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References

Bourjea J, Nel R, Jiddawi NS, Koonjul MS, Bianchi G. 2008. Sea turtle by-catch in the west Indian Ocean: review, recommendations and research priorities. *Western Indian Ocean Journal of Marine Science.* 7(2): 137–150.

Brewer D, Rawlinson N, Eayrs S, Burridge C. 1998. An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. *Fisheries Research 36*(2): 195-215.

Brito A. 2012. An interview-based assessment of the incidental capture and mortality of sea turtles by commercial shrimp trawling off Sofala Bank, Mozambique. *Revista Moç. Investig. Pesqueira* 30: 31-56.

Broadhurst MK. 2000. Modifications to reduce bycatch in prawn trawls: a review and framework for development. *Reviews in Fish Biology and Fisheries* 10(1): 27-60.

FAO. 2007. Report of the workshop on managing interactions between sea turtles and shrimp trawl fisheries in the South West Indian Ocean. Mahajunga, Madagascar, 11-14 June 2007. Meeting Report no. 3 GCP/INT/919/JPN. FAO, Rome. 49 pp.

Fennessy ST. 1994. Incidental capture of elasmobranchs by commercial prawn trawlers on the Tugela Bank, Natal, South Africa. *South African Journal of Marine Science*. 14: 287-296.

Fennessy ST, Mwatha GK, Thiele W. eds. 2004. Report of the regional workshop on approaches to reducing shrimp trawl bycatch in the Western Indian Ocean, Mombasa, Kenya, 13-15 April 2003. Food and Agriculture Organization of the United Nations, Rome: 49p. (FAO Fisheries Report 734)

Fennessy ST, Isaksen B. 2007. Can bycatch reduction devices be implemented successfully on prawn trawlers in the Western Indian Ocean? – results of a BRD experiment in Mozambique. *African Journal of Marine Science* 29(3): 453-563.

Fennessy ST, Vincent X, Budeba Y, Mueni EM, Gove DZ. 2008. An update on initiatives to reduce prawn trawl bycatch in the Western Indian Ocean. *Western Indian Ocean Journal of Marine Science*. 7(2): 217-222.

Fennessy ST, Everett BI. 2015a. Crustacean shallow-water trawl fisheries, a retrospective analysis of their status in the Southwest Indian Ocean. Chapter 2: 19-65. In: van der Elst RP and Everett BI. 2015. (*eds*). Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species. *Oceanographic Research Institute, Special Publication,* 10. 448pp.

Fennessy ST, Everett BI. 2015b. Fisheries' bycatch, an updated assessment of the status in the Southwest Indian Ocean. Chapter 7: 287-302. In: van der Elst RP and Everett BI. 2015. (*eds*). Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species. *Oceanographic Research Institute, Special Publication,* 10. 448pp.

Isaksen B, Valdemarsen J W, Larsen RB, Karlsen L. 1992. Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly. *Fisheries Research*, *13*(3), 335-352.

Kimani E, Munga C, Ndoro C, Manyara J, Thoya P, Amisi J. 2012a. SWIOFP Survey Report, Survey number SWIOFP2011C201a: Shallow-water prawn trawl survey in Kenya, SWIOFP Component 2. Kenya Marine and Fisheries Research Institute 91 p.

Kimani E, Munga C, Ndoro C, Manyara J, Thoya P, Amisi J. 2012b. SWIOFP Survey Report, Survey number SWIOFP2011C201b: Shallow-water prawn trawl survey in Kenya, SWIOFP Component 2. Kenya Marine and Fisheries Research Institute 49 p.

Lo NCH, Jacobson LD, Squire JL. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences*. 49: 2515-2526.

Maunder MN, Punt AE. 2004. Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* 70: 141-159.

Mellet B. 2015. Ecological risk assessment of fisheries on sea turtles in the south western Indian Ocean. MSc thesis, Nelson Mandela Metropolitan University. 217 p.

Mwakosya CA, Kuguru B, Mathew S, Kulekana JJ, Sululu J, Igulu M, Kuboja B, Sekadende B, Mwaitega S, Chande M, Mgeleka S, Kayanda R, Mulela H. 2012 Assessment of crustacean stocks in the SWIOFP countries: Technical Report on the shallow water prawn trawl survey in Tanzania, February 9th – 23 and June 13th to 25th 2011. 43 p.
Razafindrainibe H. 2010. Baseline study of the shrimp trawl fishery in Madagascar and strategies for bycatch management. Report for the United Nations Food and Agriculture Organization, Rome (Project TCP/MAG/3201-REBYC3202). 111 p.
Stobutzki, I., Miller, M., Brewer, D. (2001). Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch. Environmental Conservation 28, 167-181.
Tonks, M.L., Griffiths, S.P., Heales, D.S., Brewer, D.T., Dell, Q. (2008). Species composition and temporal variation of prawn trawl by-catch in the Joseph Bonaparte Gulf, northwesten Australia. Fisheries Research 89, 276-293
Wallace BP, Lewison RL, McDonald SL, McDonald RK, Kot CY, Kelez S, Bjorkland RK, Finkbeiner EM, Helmbrecht S, Crowder LB. 2010. Global patterns of marine turtle bycatch. *Conservation letters 3*(3): 131-142.
Wamukoya G , Mbendo J. 1995 Incidental capture of sea turtles in shrimp trawl fisheries in Kenya. KWS Technical Series. Mombassa: Kenya Wildlife Service. 6 p.
Wamukoya GM, Salm RV. (eds.). 1997. Proceedings of the Western Indian Ocean turtle excluder device (TED) training workshop, Mombasa, Kenya, 27-31 January 1997, IUCN. 30pp.
Watson J W. 1989. Fish behaviour and trawl design: potential for selective trawl development. In: *Proceedings of the World Symposium on Fishing Gear and Fishing Vessels. Marine Institute, St. Johns, Canada* pp. 25-29.

Appendix 1

Short report on a fact-finding mission on TEDs in Madagascar (WIOMSA Project BYCAM)

Prepared by Sean Fennessy (ORI), Lizette Sousa (IIP), Samuel Sitoe (ADNAP)

Location + Date
Mahajunga, 22-26 February 2015; Antananarivo, 27 February 2015

General purpose of the mission
To obtain practical information on the experience of Madagascar with TEDs, so as to facilitate TED implementation in Mozambique

Methods
Interviews with fishing companies and researchers

General
The BYCAM participants were hosted by Jean-Jacques BE and Herimamy RAZAFINDRAKOTO from the Centre d´Etudes et de Développement des Pêches (CEDP) of the Madagascar Ministry of Fisheries and Marine Resources in Mahajunga. Discussions were held with directors and/or trawler captains from four fishing companies (RefrigePeche, PêcheExport, UNIMA, SomaPêche) in Mahajunga. In Antananarivo, Sean Fennessy also met with representatives of GAPCM (Groupement des Armateurs à la Pêche Crevettière de Madagascar), a society comprised of representatives of the fishing industry, aquaculture and various government bodies.

OBJECTIVES

1 Selection of appropriate TED

a) Consideration of shrimp trawl specifications in Madagascar + Mozambique

There are 40 industrial trawlers in Madagascar, a very similar number to Mozambique. Mesh size in the body of the trawl in Madagascar is 60 mm, and all vessels use four nets on booms; trawl duration is 1-2 hours. Apart from the use of 50 mm codend mesh in Madagascar versus 55 mm in Mozambique, the fishing gear in the two countries is very similar, and according to one of the captains, using the Malagasy TEDs will not be a problem.

b) TED design, materials

TEDs were inspected on trawlers in the fishing harbour at two fishing companies (Refrigepêche and PêcheExport); TEDs were already installed in the nets in preparation for the new season commencing 5 March 2015.

Companies reported that they all use the same TED design (Figure 1) which uses United States specifications (although the first TEDs used in Madagascar were imported from Australia), with minor modifications (e.g. rectangular or round bars – Figures 1-3).

Some of the first TEDs used in 2005 are still being used today – the companies repair them, or import new TEDs, or build them at their workshops using the same design. Aluminium is mainly used; although Innox (stainless steel) is sometimes used. Bycatch Reduction Devices (big-eyes) are also compulsory although these were not observed.

The design specifications are not included in legislation and could not be provided to us by the companies or GAPCM; however, obtaining specifications should not be a problem as they are available on the internet.

Figure 1: Typical TED used in Madagascar

Figure 2: Round bars and rectangular bars in TEDs

c) Installation specifications, modifications (flaps, floats, etc.)

TEDs are installed in an extension piece in the beginning of the codend. The main criterion is that a 45^{o} grid angle is the maximum allowed. Individual captains make small modifications when installing the TEDs in their nets. All TEDs observed used a double flap cover for the escape opening (Figure 3), to prevent excessive loss of shrimp. Some TEDs use one large float while some use two smaller floats to help grid alignment.

Figure 3: Double flaps (the dark green mesh which is folded back) are used to cover the escape opening; a single large float is used on this TED; there is a mixture of round and square bars in this TED.

2 Perspectives on TED use in Madagascar

a) Industry (TED benefits, problems with using TEDs, catches)

The director of one of the companies said that when they started to use TEDs, 50% of the catch was lost, but this improved later; these days they believe the TEDs lose 5-10% of big shrimp. The TEDs and BRDs also lose big fish, which reduces profitability; in 2005-2007, shrimp catches were good and profitability was OK, but this has changed (fuel price increase, shrimp catch rates reduced) so now they need the bycatch to help profitability. The TEDs do not improve shrimp quality; TEDs helped them to be able to use eco-labels on their product, but this did not improve their access to markets (there are several eco-labels - Red Label, MSC, EcoPêche, with different criteria). The markets in Europe have improved now, so consumers have less concern about eco-labels. The company said that if they were allowed, they would remove the TEDs although they do understand that the TEDs help the ecosystem. In 2004, before TEDs were used, they caught 8 turtles (1 dead) in that season. They do not have a problem with the physical operation of the TEDs i.e. the TEDs do not cause problems to the operation of the trawl nets.

Another company did their own experiment to test the effect of the TEDs in 2013 (reported earlier in this document), but there was no independent observer onboard; without a TED, small shrimp catch increased 5-10%, large shrimp increased 20% and retained fish increased by 30%. The director believes that reducing the predatory fish (which are released by the TEDs) has resulted in reduced shrimp; they have disrupted the balance of the ecosystem. However, he was not able to say why shrimp catches have also declined in Mozambique where TEDs are not used. They have only caught two turtles since 2009. This company met with MSC representatives who said that TEDs are not essential for MSC certification. They are concerned about profitability – some companies have closed as a result of the poor catches. Apparently this company has recently invested in large (45 m trawlers) and their bycatch is exported; they need to show profitability.

The third company's director was OK about using TEDs, and said they only lose 5% of catch. Eco-labelling of their products is not a concern. They use TEDs because of ecosystem concerns, and it is a legal requirement. One of the trawler captains said TEDs cause 20% loss in catch. When fishing in Nosy-Be area (some years ago), he once caught 15 turtles. The company does not use any eco-labelling and don´t have any problems with marketing the product. One of the local Malagasy captains said it takes about two hours to change a damaged TED onboard (they carry four spares). They normally install the TED into the extension away from the vessel, and this extension is later attached to the main trawl net in front of the codend. Branches sometimes clog the TEDs, especially on the east coast in the beginning of season.

We only met a trawler captain from the fourth company as the director was not available. He did not have problems with the operation of the TEDs, although he had only been a captain for two years, and could not say whether the TEDs caused a loss in catch.

b) Management (monitoring methods + results, compliance success)

The Malagasy legislation only says that TEDs and BRDs must be used – there are no specifications given. GAPCM also said that there are no specifications given to the companies – they are still using the same design which was implemented in 2005. The 45^{o} grid angle is generally known and used, and bar spacing is about 11 cm. There has been no independent testing of TEDs in Madagascar after IFREMER's assistance in 2003-2005, apart from a one-day trial during an FAO TED workshop in Mahajunga in 2007. In the workshop report, the FAO and US gear experts noted that the Malagasy double flap system could be improved, and that their TED angles were less than the optimum; the grid angles need to be checked frequently, as the nets stretch with time. The perspective from GAPCM is to use TEDs so as reduce environmental impacts by trawling; they would like to improve the operation of the TEDs so as to minimize loss of shrimp, as the requirement for the use of TEDs causes conflict at their meetings.

Regarding compliance, there is inspection of fishing gear at sea – but not on specifics such as the optimum angle for the grid. One of the captains said his boat was inspected at sea 3-4 times per season. All boats observed in the harbour appeared to have TEDs installed, or were at least ready for installation. One of the people interviewed suggested that it is possible that the trawler crews sometimes remove the TEDs at sea.

3 Arrangements for TED tests in Mozambique.

A very experienced trawler captain said that he was available to come to Mozambique to train local captains in the installation and use of TEDs; he was available from September to January. The cost of this training needs to be established. The timing of this training would have to be appropriate for the Mozambique industry, so that trawler captains and/or fishing masters were available (the best time is close to the opening of the season). However, it seems that the specifications/installation of TEDs in Madagascar can be improved, so consideration should rather be given to obtaining practical advice from another gear expert with more recent information, so as to maximize the chances of success in implementation of TEDs in Mozambique.