Received: 5 September, 2012

IOTC–2012–WPEB08–33

EFFECT OF HOOK STYLE AND BAIT TYPE ON THE INCIDENTAL BYCATCH OF SEA TURTLES ON THE PORTUGUESE PELAGIC LONGLINE FISHERY: LESSONS FROM THE ATLANTIC OCEAN

Miguel N. Santos*, Rui Coelho, Sérgio Amorim & Joana Fernandez-Carvalho

SUMMARY

This scientific document briefly reports some of the major results of the SELECT-PAL Project, which aimed to evaluate the effect of hook style and bait type on the catches of major target and by-catch species of the Portuguese pelagic long-line fishery on different areas of the Atlantic Ocean (NE tropical, Equatorial and Southern temperate). A total of 733 long-line sets were carried out, namely 202 in the NE Tropical, 221 in the Equatorial and 310 in the Southern Atlantic. Three different hook types were tested, traditional J hook (9/0) and two 17/0 circle hooks (a non-offset and a 10º offset), but only one bait type was used in each set (*Scomber* spp. or *Illex* spp.). Overall, a total of 1,006,272 hooks were set (335,424 of each hook style). The highest mean sea turtle BCPUE (J hook baited with squid) was observed on the Equatorial area (1.83/1000hooks), followed by the Southern and North-eastern tropical areas, respectively. The highest mean BPUE values for sea turtle species combined and for the individual species occurred with the J style hook. The 10º offset circle hook baited with mackerel provided the highest reduction of sea turtle by-catch rates. Although hook location was species-specific, most turtles were caught by the mouth, the exception being leatherbacks which were mostly entangled or hooked by the flippers. For the target species (swordfish) the CPUEs were higher with J style hooks baited with squid, where as for tropical tunas (bigeye and yellowfin) only the bait effects were significant. On the other hand, mean shark CPUEs tended to be higher with the use of circle hooks baited with mackerel.

KEYWORDS: Marine turtle bycatch; J *vs.* circle hooks; squid *vs.* mackerel bait; Portuguese pelagic longline; Atlantic Ocean.

1: Instituto Português do Mar e da Atmosfera (IPMA), Av. 5 de Outubro s/n, 8700-305 Olhão, PORTUGAL

*: Corresponding author e-mail: mnsantos@ipimar.pt

1. Introduction

Marine fisheries are the major anthropogenic influence on marine systems worldwide, affecting marine animal populations and ecosystem function (Jackson et al., 2001; Pauly et al., 2005). Among the different issues in marine fisheries, by-catch - the unintended capture of non-target organisms during fisheries operations, is a major problem (Hall et al. 2000; Soykan et al. 2008). Among the marine megafauna which are commonly incidentally caught, sea turtles are of special concern. In fact, six of the seven extant species of sea turtles living in the world's oceans are listed as either critically endangered or endangered (IUCN, 2012), and international trade of these species is prohibited. One of the main causes for the worldwide failure of most sea turtle populations to recover is their incidental capture in fisheries, as they occupy broad geographic ranges spanning geopolitical boundaries and oceanographic regions that support many different fisheries (Hillestad et al. 1995; Lutcavage et al. 1996; Wallace et al., 2010). Among the different fishing gears, trawls (Magnuson et al. 1990; Poiner and Harris, 1996; Lewison and Crowder, 2007), gill nets (De Metrio and Megalofonu, 1988; Julian and Beeson, 1998) and longlines (Witzell, 1999; Lewison et al., 2004; Carranza et al., 2006; Cambiè et al., 2010) are known to interact with sea turtles worldwide.

A number of studies aiming to investigate mitigation measures for bycatch of sea turtles on the pelagic longline fisheries have been conducted worldwide (see reviews by Read, 2007 and Wallace et al., 2010; Bulletin of Marine Science special issue, 2012). However, in the ICCAT convention area, these studies are mostly limited to the Northern Hemisphere. Moreover, to the authors best knowledge those few studies conducted on the Equatorial (Carranza et al., 2006) and SW areas, were limited in terms of the number of sets and area covered.

In order to increase the area covered for such studies and the information on sea turtle incidental catch in the Atlantic Ocean, the Portuguese Fisheries and Aquaculture Directorate and a private fishing company (PESCARADE LDA.) are funding an ongoing research project (SELECT-PAL - *Redução das capturas acessórias na pescaria de palangre de superfície*) within the scope of the PROMAR Program. The aim of the project is to test the effect hook style and bait type on the catches of target, non-target and bycatch species from the pelagic longline fishery, along three major areas of activity of the Portuguese pelagic longline fleet in the Atlantic Ocean: NE tropical, Equatorial and Southern temperate. Some of the results of this project have been already published (Santos et al., 2012a; Coelho et al., 2012) and presented to ICCAT (Santos et al., 2012b, c). The present document reports the major results achieved regarding the effect of different combinations of hook style and bait type on the incidental bycatch of marine turtles in three major areas of activity of the Portuguese pelagic longline fishery in the Atlantic Ocean.

2. Material and methods

For this study, a total of 733 longline sets were carried out along three regions of the Atlantic Ocean (**Figure 1**), between October 2008 and February 2012. Two commercial boats belonging to the Portuguese pelagic longline fleet were involved in the fishing trials: ALMA LUSA (PM-1269-N) and PRÍNCIPE DAS MARÉS (PM-1218-C).

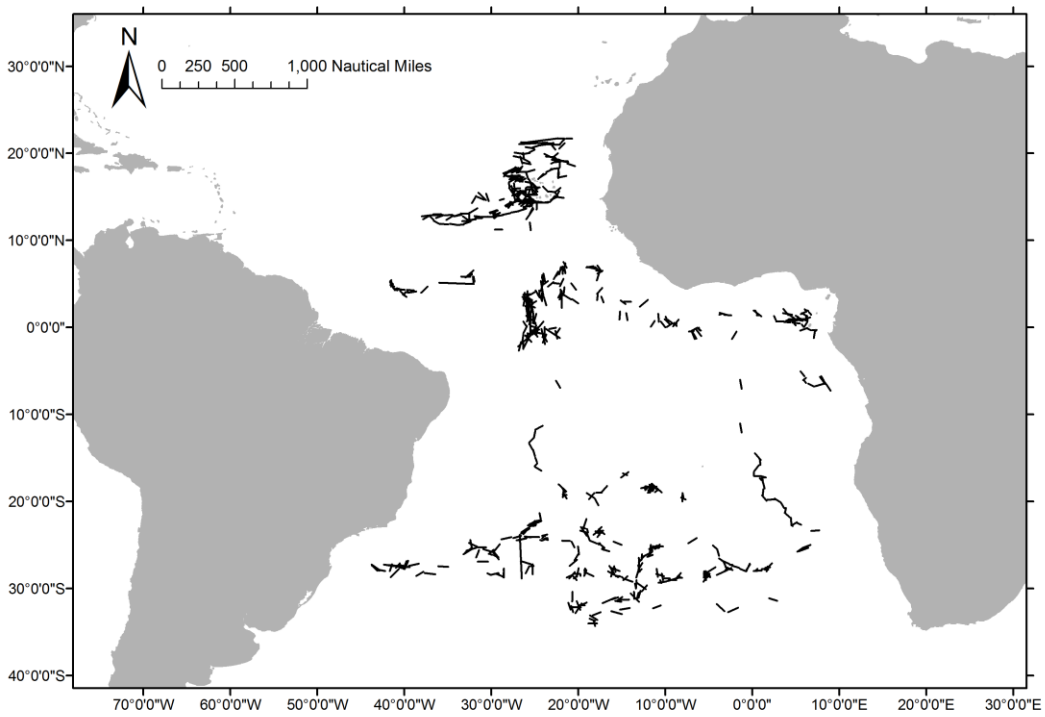

Figure 1: Location of the 733 experimental longline sets in the three regions of the Atlantic Ocean.

The fishing gear was similar for both vessels, consisting of a standard monofilament polyamide mainline of 3.6 mm of diameter, with five branch lines between floats. Each branch line was 18 m in length, the 1st part consisting of 2.5 mm monofilament connected by a swivel to a 2.2 mm monofilament gangion in the case of the Southern and Equatorial areas or to a multifilament wire leader in the tropical area, with a hook in the terminal tackle. A battery flashlight (green color) was attached to each gangion. Overall a total of 1,006,272 hooks were used, fishing at depths of 20-50 m. Gear deployment begun traditionally at 17:00 hr, with haulback (gear retrieval) starting the next day from about 06:00 hr. Three different stainless steel hook styles (produced by WON YANG, Korea) were used in each longline set. The control corresponding to the traditional J hook on the fishery (EC-9/0-R), and the treatments corresponding to: G hook, a non-offset circle hook (H17/0-M-S); and Gt hook, a 10º offset circle hook (H17/0-M-R). The characteristics of the different hooks are summarized in **Table 1** and a photograph is provided in **Figure 2**. Hook style was alternated section by section of the longline (each section containing between 70-80 hooks), to minimize the potential for confounding effects specific to a set (e.g. location, water temperature, turtle density, or other factors). Moreover, the hook style of the first section in the water changed every set, following a fixed scheme (i.e., J:G:Gt:J:G:Gt, and so on). Two different bait types were used, squid (*Illex* spp.) corresponding to the control and mackerel (*Scomber* spp.) as the treatments, but only one bait was used in each set to avoid possible interaction effects, as suggested by Watson et al. (2005). Standardized bait was used in all longline sets (squid 27.8±0.97 cm and mackerel 35.1±1.19 cm).

Table 1: Details of the different hook styles used in the study. Standard deviation is indicated between parentheses.

Parameter	Hook style		
	J (EC-9/0-R)	G (H17/0-M-S)	Gt (H17/0-M-R)
Total length (mm)	87.2 (±1.11)	77.7 (±0.92)	
Front length (mm)	40.4 (±1.10)	43.9 (±0.45)	
Maximum width (mm)	43.3 (±0.64)	49.4 (±0.88)	
Gap (mm)	33.2 (±0.59)	27.0 (±0.51)	
Arm diameter (mm)	5.0 (±0.00)	5.0 (±(0.00)	
Offset angle	10º	0º	10º

Figure 2: Photograph of the three hook styles used during this study: J hook 10° offset (left); Gt circle hook 10° offset (middle); and G non-offset circle hook (right). Hook measurements in Table 1.

All characteristics of the fishing gear and fishing practices (e.g. hook placement, setting time, use of light, bait size and hook manufacturer) were standardized between the two vessels. However, length of mainline and number of hooks were allowed to vary among vessels to take into consideration vessel operating capacity and the sea condition.

Whenever a sea turtle was caught in the longline, the fishery observer aboard the fishing vessel identified the species and recorded the hook style used, the bait, the condition of the turtle (alive/dead), the location of the hook (flippers/mouth/esophagus/entangled) and the condition when released to the sea (alive/dead). Further, and whenever possible, the sex of each specimen was determined and the carapace curved length and width were measured to the nearest lower 1 cm. However, the size of leatherbacks was only recorded for a limited number of specimens, due to the fact that most turtles were released by cutting-off the fishing line, as a result of their size and weight.

All other specimens caught were also identified and measured. Additional information was recorded on sex (for elasmobranchs), condition at-haulback (alive/ dead), specimen's fate (retained/discarded) and its condition if discarded (alive/dead). However, such data is not presented in the present paper.

Following Watson et al. (2005), power tests were carried out in order to estimate the experimental fishing effort required to detect a fishing method that has different degrees of effectiveness in reducing bycatch of sea turtles in comparison with the control fishing method. The control fishing method was assumed to be the combination most commonly used in the fishery, specifically J type hooks baited with squid, and the power calculations were based on the necessary number of hooks required to detect a 25% and 50% reduction bycatch rate in the case of major species bycaught in each of the three geographical areas surveyed.

3. Results

As previously mentioned, a number of studies on marine turtle bycatch on pelagic longline fisheries have been conducted worldwide. However, only a few trial studies were conducted on the NE Tropical, Equatorial and Southern Atlantic, most being limited in terms of the number of sets, geographical area covered and bait types used. Therefore, to the authors' best knowledge, the present study is the most extensive one, following a strict experimental design, aiming to assess the effect of hook style and bait type on sea turtle incidental bycatch on the swordfish pelagic longline fishery in those areas.

In the present paper only major results are presented as a general overview of the main results achieved. More detailed information on the data analysis and results (and discussion) are available on Santos *et al.* (2012a,b and c).

3.1. Sea turtle bycatch rates

Overall a total of 722 sea turtles were caught, specifically: i) 183 leatherbacks *Dermochelys coriacea* (Vandelli 1761) and 22 loggerheads *Caretta caretta* (Linnaeus 1758) in the Northeastern Tropical area; ii) 161 olive ridley *Lepidochelys olivacea* (Eschscholtz 1829), 58 leatherbacks, 10 loggerheads and 2 Kemp's ridley *Lepidochelys kempii* (Garman 1880) in the Equatorial area; and iii) 260 loggerheads and 26 leatherbacks in the Southern temperate area.

Most of the longline sets had either zero or very limited catches of sea turtles. In fact, 535 longline sets (73%) had zero by-catches of any sea turtle, varying from 67.9% in the Equatorial region to 78.4% in the Southern region. The maximum number of specimens caught in a single set was 22, but that particular set was an extreme outlier (that occurred on the NE Tropical region), since for most of the sets less than five sea turtles were caught.

The highest mean BPUEs for species combined in each of the surveyed regions were observed on the: i) south-western part of the NE tropical area; ii) central part of the Equatorial area, between 8ºW and 27ºW; and iii) western part of the Southern area, between 37ºW and 44ºW. **Figure 3** shows the spatial distribution of BPUE by longline experimental set, for the major sea turtles species caught and the three surveyed Atlantic areas.

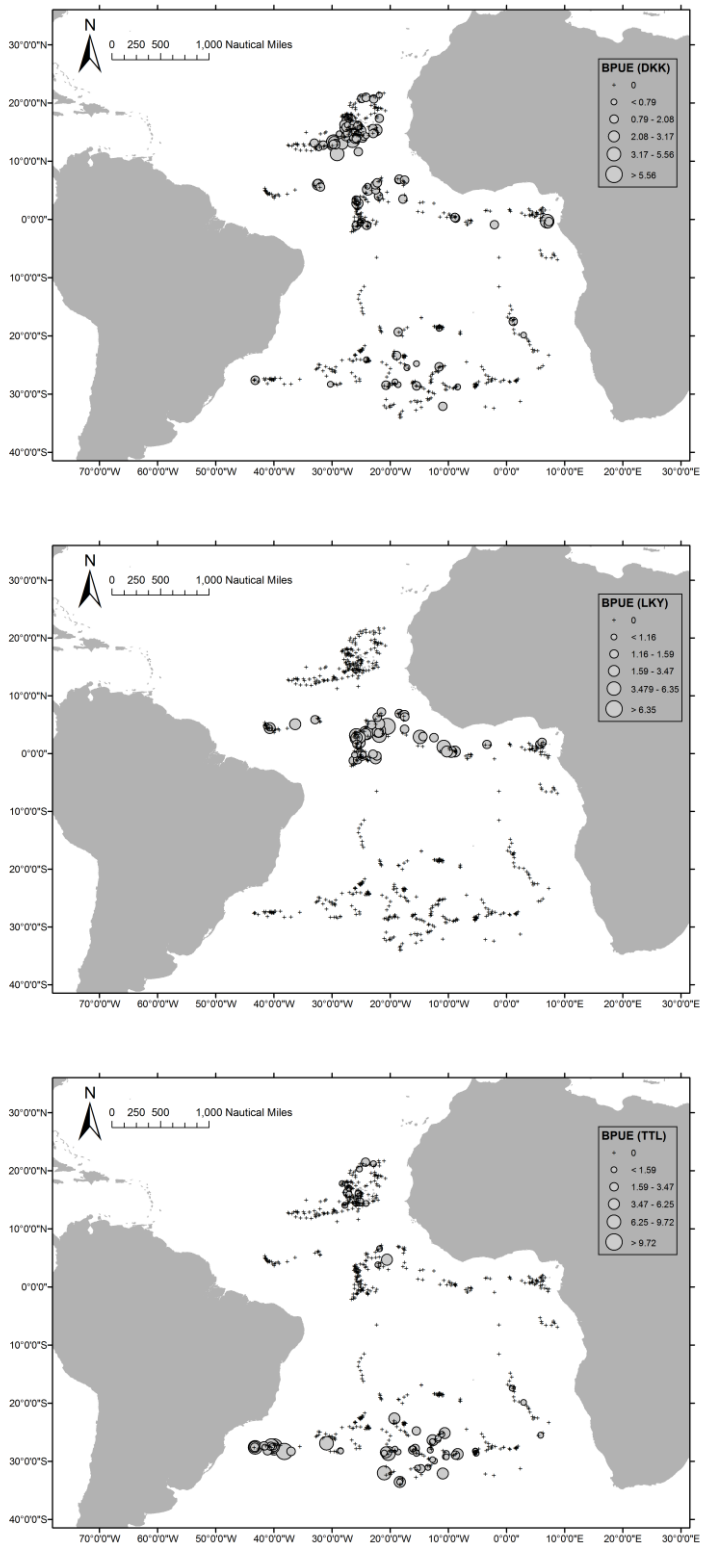

Figure 3: Spatial distribution of BPUE by longline experimental set, for the major sea turtles species caught: leatherback (DKK - *D. coriacea*, top), olive ridley (LKV – *L. olivacea*, middle) and loggerhead (TTL - *C. caretta*, bottom). The size of the circles is proportional to the BPUE and the dark crosses represent fishing sets with 0 catches.

Because of the high number of sets with 0 catches, the mean BPUE values were generally very low. Overall, the highest mean BPUE values for species combined and for the individual species occurred with the J style hook, while the catches with both circle hooks tended to be much lower (**Figure 4**). Mean observed BPUEs for the control (J hook baited with squid) are summarized in **Table 2**, by surveyed region for species combined and major species caught. For species combined the mean BPUE varied between 1.23 (±2.87) in the NE Tropical area to 1.83 (±3.71) in the Equatorial area. By species, the highest BPUE was recorded for loggerheads (1.51±3.502) caught in the Southern area, followed by Olive ridleys' (1.22±2.777) and leatherbacks on the Equatorial and NE Tropical areas, respectively.

The BPUE ratio between the standard fishing practice (J hook baited with squid) and the other hook:bait combinations tested showed, for species combined, reductions on BPUE between 0.9-3.1, 2.0-8.4 and 1.7-6.4 times for the NE Tropical, Equatorial and Southern Temperate areas, respectively (**Table 3**).

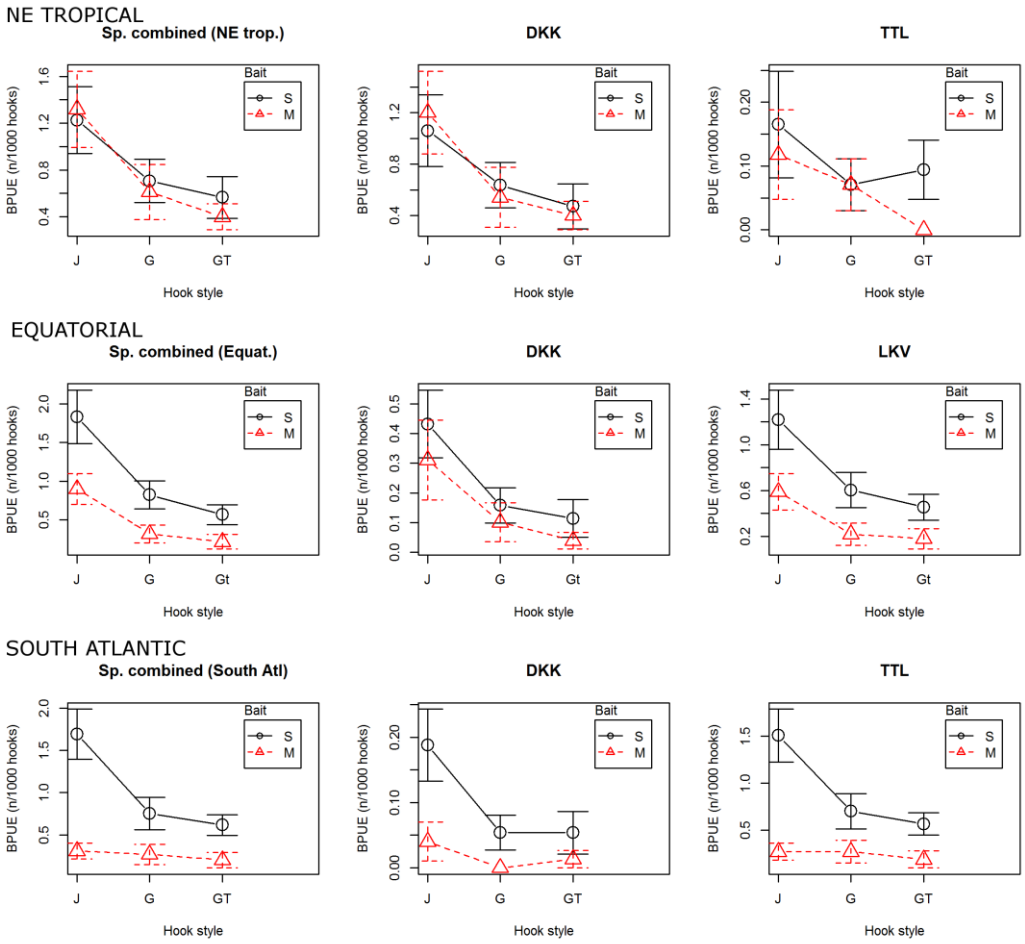

Figure 4: Mean BPUEs (with the respective standard errors) observed with the different hook styles (J, G and Gt) and bait combinations (M – mackerel and S – squid), for the species combined and major species caught by geographical area surveyed (Top - NE Tropical; Middle – Equatorial; Bottom – Southern). Leatherbacks (DKK - *D. coriacea*), olive ridley (LKV – *L. olivacea*) and loggerheads (TTL - *C. caretta*).

Table 2: Mean bycatch per unit of effort (n/1000 hooks) for species combined and major sea turtle species for the three Atlantic areas surveyed obtained by the control hook:bait combination (J style kook baited with squid). Standard deviation (StD) is indicated between parentheses.

Geographical area	Sea turtle species	Mean BPUE (± StD)
NE Tropical	Species combined	1.23 (±2.869)
	Leatherback	1.06 (±2.807)
	Loggerhead	0.17 (±0.842)
Equatorial	Species combined	1.83 (±3.713)
	Olive ridleys'	1.22 (±2.777)
	Leatherback	0.43 (±1.226)
Southern Temperate	Species combined	1.69 (±3.684)
	Loggerhead	1.51 (±3.502)
	Leatherback	0.18 (±2.869)

Table 3: Ratio between the mean BPUE obtained with the standard fishing gear (J hook baited with squid - control) and the different combinations of hook style (J – traditional 10º off set 9/0 hook used on the fishery; G – 0º offset 17/0 circle hook; Gt – 10º offset 17/0 circle hook) and bait type (S – squid; and M – mackerel) tested, for species combined and for the two sea turtle species caught.

Northeastern Tropical area			
Comparison	Loggerhead	Leatherback	Combined species
J_S *vs.* G_S	2.3	1.7	1.7
J_S *vs.* Gt_S	1.8	2.3	2.2
J_S *vs.* G_M	2.3	2.0	2.0
J_S *vs.* Gt_M	-	2.6	3.1
J_S *vs.* J_M	1.4	0.9	0.9
Equatorial area			
Comparison	Olive Ridley	Leatherback	Combined species
J_S *vs.* G_S	2.2	2.7	2.2
J_S *vs.* Gt_S	3.2	3.8	3.2
J_S *vs.* G_M	5.6	4.3	5.7
J_S *vs.* Gt_M	6.8	11.0	8.4
J_S *vs.* J_M	2.1	1.4	2.0
Southern Temperate area			
Comparison	Loggerhead	Leatherback	Combined species
J_S *vs.* G_S	2.2	3.5	2.3
J_S *vs.* Gt_S	2.7	3.5	2.7
J_S *vs.* G_M	5.6	-	6.3
J_S *vs.* Gt_M	8.00	14.0	8.4
J_S *vs.* J_M	5.6	4.7	5.5

3.2. Hooking location

Hooking location was species specific regardless of the hook style and bait type used. In fact, leatherback turtles were almost exclusively retained by the flippers or entangled in the gear, while most oliver ridley and loggerheads were hooked either by the mouth (most cases) or swallowed the hook and were hooked by the esophagus (**Figure 5**).

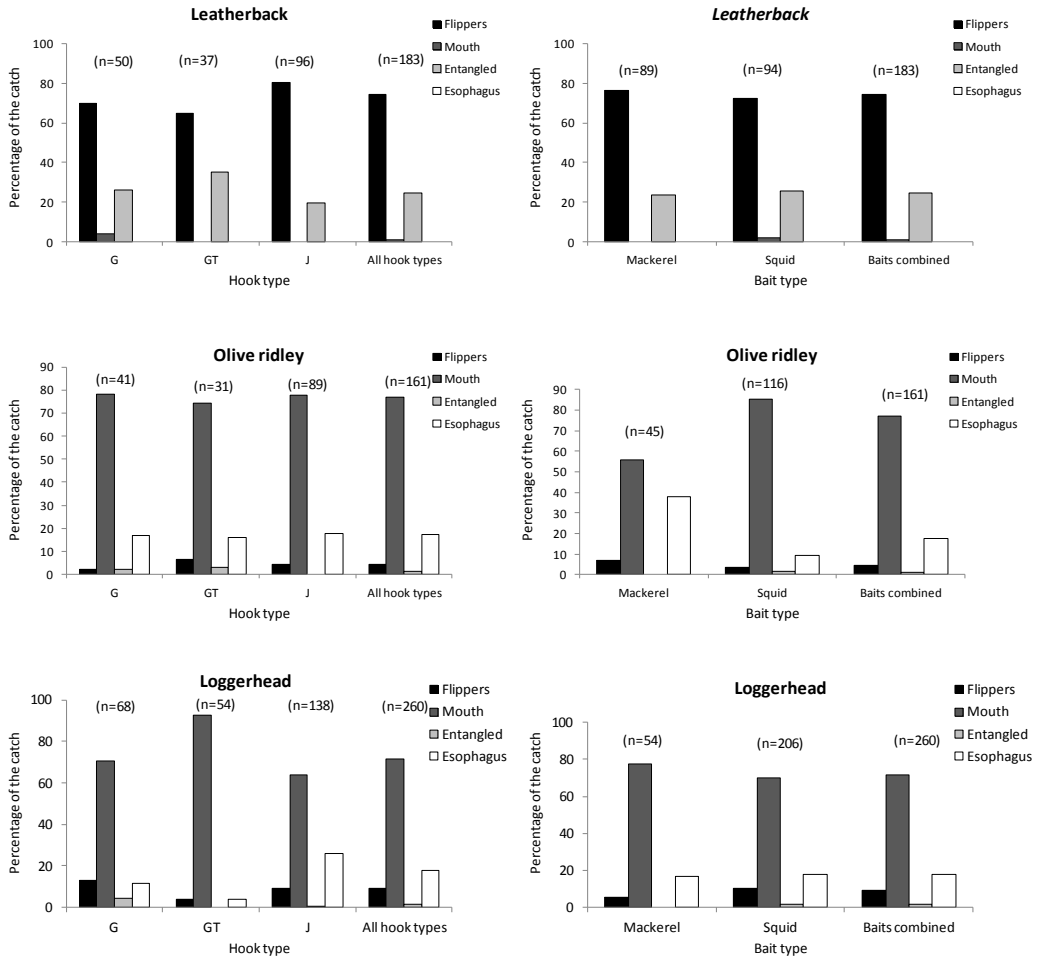

Figure 5: Percentage of hooking location per hook style (left) and bait type (right) for the major sea turtle species caught in each of the three surveyed Atlantic areas: NE Tropical (top), Equatorial (center) and Southern temperate (bottom).

3.3. Mortality

Most of the sea turtles caught during the experimental fishing trials were captured and released alive, regardless of the hook style and bait used. The hooking location seems to have a great impact on mortality with most specimens caught by the flippers or entangled being alive at the time of haulback (> 85%), while the specimens hooked in the mouth and the esophagus had lower percentages of alive specimens (between 40% and 80%).

For the factor hook style, and considering all species combined, the G style hook had proportionally more turtles alive than dead, with the percentage of alive specimens decreasing

for the J and Gt style hooks. When the data corresponding to the leatherback caught in the NE Tropical area was analyzed separately, the proportions of alive specimens were very high for all hook types, specifically 100%, 82% and 80% for hook types G, J and Gt, respectively (**Figure 6**). In the Equatorial area the proportion of alive olive ridley specimens was 80.5%, 48.4% and 69.7% for hook types G, Gt and J, respectively (**Figure 6**). Finally, for loggerheads caught in the Southern temperate Atlantic, the percentage of alive specimens ranged from 83%, 62% and 50% for hook types Gt, J and G, respectively (**Figure 6**).

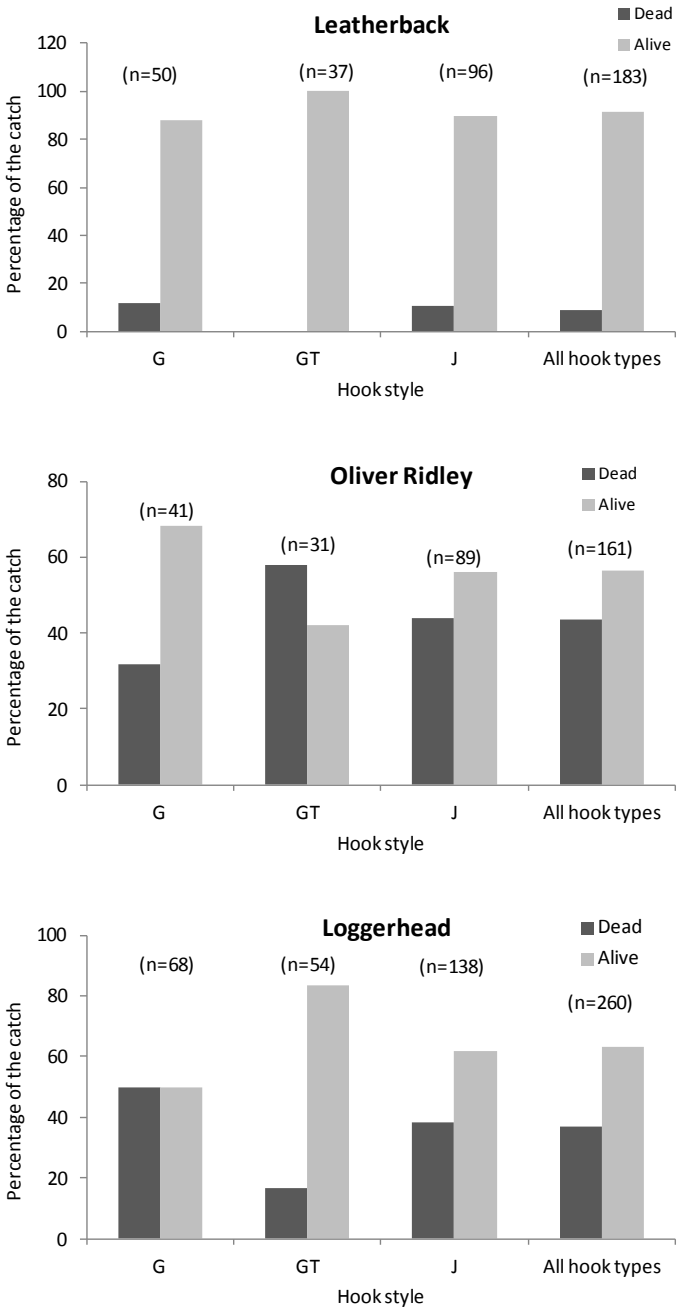

Figure 6: Percentage of fishing mortality at-haulback per hook style for the major sea turtle species caught in each of the three surveyed Atlantic areas: NE Tropical (top), Equatorial (center) and Southern temperate (bottom).

When the factor bait was analyzed separately, and considering all species combined and major sea turtle species separately, the bait type by itself does not seem to influence mortality. Overall, many more turtles were caught when squid was used as bait than with mackerel, but the observed versus expected frequencies of dead and alive turtles caught with each bait type were not significantly different.

3.4. Bycatch at size

Loggerheads caught in the NE Tropical area ranged in size from 42 to 77 cm total curved length and averaged 61.8 (±10.66) cm, while those caught in the Southern Atlantic ranged from 41 to 78 cm and averaged 61.5 (±6.09) cm. Olive ridleys caught in the Equatorial area ranged in size from 43 to 71 cm total curved length and averaged 60.4 (±5.81) cm. On the other hand, leatherback turtles ranged from 48 to 187 cm total curved length, but only a limited number of were measured due to their large size as most specimens ended up being released by the crew without being brought to the fishing vessel (particularly the larger specimens). The size statistics for these species caught are shown in **Table 4**.

Table 4. Statistics of the size structure of the all turtle species caught. N - total number of specimens caught; n - number of specimens measured; Min – minimum; Max – maximum; StD - standard deviation. Measurements refer to the total carapace curve length (cm).

				Total curve length (cm)			
Geographical area	**Species**	**N**	**n**	**Min**	**Max**	**Mean**	**StD**
NE Tropical	Loggerhead	260	234	41	78	61.5	6.09
	Leatherback	26	11	48	140	92.9	33.82
Equatorial	Olive ridleys'	161	148	43	71	60.4	5.81
	Leatherback	58	15	46	151	101.8	43.45
	Loggerhead	10	10	73	77	74.7	1.25
	Kemp's ridley	2	2	58	59	58.5	0.71
Southern Temperate	Loggerhead	22	20	42	77	61.8	10.66
	Leatherback	183	48	62	187	118.5	33.68

4. Acknowledgments

This study was carried out within the scope of the SELECT-PAL project (Programa PROMAR Proj. 31-03-05-FEP-1). Thanks are due to the crews of fishing vessels *Alma Lusa* (PN-1269-N) and *Príncipe das Marés* (PM-1218-C) for their cooperation and commitment during the course of the study. Thanks are also due to the technicians J. Táta Regala, I. Ribeiro, Sérgio Goes and

Francisco Leitão for collecting the data. R. Coelho was supported in part by a grant from FCT (Ref: BDP 40523/2007) co-funded by "POCI-2010 Programa Operacional Ciência e Inovação 2010" and "FSE Fundo Social Europeu". During part of this work J. Fernandez-Carvalho was supported by a grant from FCT (Ref: BD 60624/2009).

5. References

Cambiè G, Camiñas JA, Franquesa R, Mingozzi T. 2010. Fishing activity and impacts along the main nesting area of loggerhead sea turtle Caretta caretta in Italy: overwhelming discrepancy with the official data. *Sci Mar*, 74 (2): 275-285.

Carranza A, Domingo A, Estrades A. 2006. Pelagic longlines: A threat to sea turtles in the Equatorial Eastern Atlantic. *Biol Conserv*, 131:52-57.

Coelho R, Santos MN, Amorim S. 2012. Effects of hook and bait on targeted and bycatch fishes in an equatorial Atlantic pelagic longline fishery. *Bull Mar Sci*, 88 (3): 449-467.

De Metrio G, Megalofonu P. 1988. Mortality of marine turtles (*Caretta caretta* L., and *Dermochelys coriacea* L.) consequent to accidental capture in the Gulf of Taranto. *Rapp P-V Reun Comm Int Explor Sci Mer Mediterr*, Monaco, 31: 285p.

Hall MA, Alverson DL, Metuzals KI. 2000. Bycatch: problems and solutions. *Mar Poll Bull*, 41: 204-219.

Hillestad HO, Richardson JI, McVea C Jr., Watson JM Jr. 1995. Worldwide incidental capture of sea turtles. *In*: *Biology and conservation of sea turtles*. Revised edition. Bjorndal KA, editor. Washington D.C.: Smithsonian Institute Press: 489–495.

IUCN. 2012. IUCN Red List of Threatened Species. Version 2012.1. http://www.iucnredlist.org/ [July 2012]

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science*, 293: 629–638.

Julian F, Beeson M. 1998. Estimates of marine mammal, turtle, and seabird mortality for two California gillnet fisheries: 1990–1995. *Fish Bull*, 96 (2): 271–284.

Lewison RL, Crowder LB. 2007. Putting longline bycatch of sea turtles into perspective. *Conserv Biol*, 21 (1): 79-86.

Lewison RL, Freeman SA, Crowder LB. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. *Ecol Lett*, 7: 221–231.

Lutcavage ME, Plotkin P, Witherington B, Lutz P. 1996. Human impacts on sea turtle survival. *In*: Lutz PL, Musick JA, editors. *The biology of sea turtles*. New York: CRC Press. p. 387–409.

Magnuson JJ, Bjorndal KA, Dupaul WA, Graham GL, Owens FW, Peterson CH, Pritchard PCH, Richardson JI, Saul GE, West CW. 1990. *Decline of the sea turtles: causes and prevention*. 1st ed. Washington D.C: National Academy Press.

Pauly DP, Watson R, Alder J. 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. *Philos T Roy Soc B*, 360: 5–12.

Poiner IR, Harris ANM. 1996. Incidental capture, direct mortality and delayed mortality of sea turtles in Australia's northern prawn fishery. *Mar Bio*, 125: 813–825.

Read A. 2007. Do circle hooks reduce the mortality of sea turtles in pelagic longlines? A review of recent experiments. *Biol Conserv*, 135: 155-169.

Santos MN, Coelho R, Fernandez-Carvalho J, Amorin S. 2012a. Effects of hook and bait on sea turtle catches in an Equatorial Atlantic pelagic longline fishery. *Bull Mar Sci*, 88 (3): 683-701.

Santos MN, Coelho R, Fernandez-Carvalho J, Amorin S. 2012b. Effects of hook type and bait on sea turtles bycatch in a Southern Atlantic swordfish longline fishery. *ICCAT Working Document* SCRS/2012/090: 19 p.

Santos MN, Coelho R, Amorin S. 2012c. Preliminary results on the use of 17/0 circle hooks and mackerel on sea turtles bycatch in a North-eastern tropical Atlantic swordfish longline fishery. *ICCAT Working Document* SCRS/2012/090: 15 p.

Soykan CU, Moore JE, Zydelis R, Crowder LB, Safina C, Lewison RL. 2008. Why study bycatch? An introduction to the Theme Section on fisheries bycatch. *Endang Spec Res*, 5:91–102.

Watson JW, Epperly S, Shah A, Foster DG. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. *Can J Fish Aquat Sci*, 62: 965-981.

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. *Conserv Lett*, 3 (3): 131–142.

Witzell, W.N. 1999. Distribution and relative abundance of sea turtles caught incidentally by U.S. longline fleet in the western North Atlantic Ocean, 1992–1995. *Fish Bull*, 97: 200–211.